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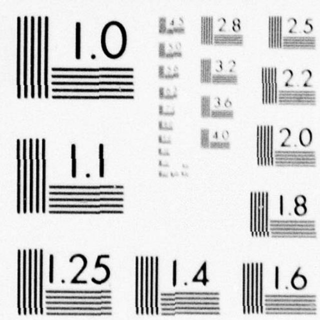


MICROCOPY RESOLUTION TEST CHART

DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-78-36

# THE AGRICULTURAL VALUE OF DREDGED MATERIAL

by

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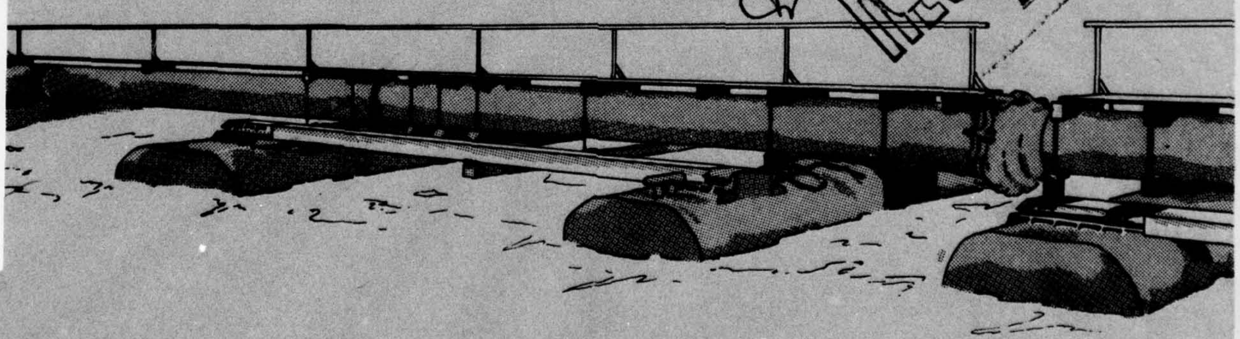

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30 September 1978

SUBJECT: Transmittal of Technical Report D-78-36

TO: All Report Recipients

1. The technical report transmitted herewith represents the results of one of several research efforts (work units) undertaken as part of Task 4C, Land Improvement Concepts, of the Corps of Engineers' Dredged Material Research Program. Task 4C was part of the Productive Uses Project (PUP) and had as a general objective determination of the technical feasibility of enhancing nonproductive land with dredged material.

2. There has been a dramatic increase in the last several years in the amount of land disposal of dredged material, necessitated largely as a result of the need for confining dredged material classified as polluted or with potential for causing adverse environmental impacts. Land for disposal activities is becoming scarce and the problem becomes more acute with the selection of each new disposal area. Attention, therefore, was directed towards identifying concepts that can increase the service life of disposal areas and thereby reduce the need for additional facilities.

3. One such concept is the application of dredged material to nonproductive agricultural land with the possibility of increasing production. The purpose of this particular study was to gather basic information about the physical and chemical properties of dredged material as they relate to its agricultural potential and to develop guidelines for determining the suitability of using dredged material as an agricultural soil or as an amendment for a marginal soil.

4. Based on the vast number of parameters involved and the newness of the concept, greenhouse experiments, as opposed to field experiments, were used to determine the suitability. Ten dredged material samples and ten marginal soil samples were collected from locations in the United States. The soils were marginal for crop production and were of such character that additions of dredged material might improve their physical and chemical properties. In addition, three productive Minnesota soils were chosen as controls. Samples of the dredged material, marginal soil, and mixtures of the two were physically and chemically analyzed prior to and after plant growth (production) experiments with three crops of ryegrass and barley.

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5. The basic conclusion is that, in many cases, dredged material can be used for agriculture production or for an amendment to a somewhat nonproductive soil. The report also presents guidelines for the disposal of dredged material on marginal soils. These guidelines cover the majority of the physical and chemical parameters involved.

6. The report also reinforces the idea that dredged material can be considered a soil resource and, when properly disposed of, could increase both agricultural production and disposal opportunities by allowing for reuse of old disposal sites.

John L. Cannon
JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

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An alternative for disposal of dredged sediments is to use them beneficially to amend marginal agricultural soils. To study the suitability of dredged material for crop production, 10 dredged material samples and 10 marginal soil samples were collected from locations in the United States. The soils were marginal for crop production and were of such character that additions of dredged material might improve their physical and chemical properties. The soils and dredged material samples were dried, ground, and mixed for plant

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growth studies and laboratory analysis. The following treatments were prepared: (a) soil alone; (b) 1/3 soil and 2/3 dredged material; (c) 2/3 soil and 1/3 dredged material; and (d) dredged material alone. In addition, three productive soils were chosen from the St. Paul, Minn., area to serve as controls in the plant growth studies.

In general, chemical properties of the dredged material samples did not differ greatly from the chemical properties of the three productive soils from Minnesota. Some of the dredged material samples were relatively high in organic matter, nitrogen, total sulfur, extractable zinc, copper, nickel, and cadmium contents. Samples high in total sulfur were also low in pH and thus had a high lime requirement. High oil and grease content of a few dredged material samples made them slower wetting than most of the soil samples. The clay fractions of many of the fine-textured dredged material samples were amorphous in nature. High organic matter content and the amorphous nature of the clay-size fraction partially explain the low bulk densities and high soil water retention capacities. Multiple regression relationships were developed which can be used for predicting water retention characteristics of dredged material, marginal soil, and their mixtures by considering the sand, silt, clay, and organic matter content and bulk density.

Three cuttings of ryegrass and two crops of barley were harvested from each of the treatments. Yields by plants in the greenhouse were greater for all fine-textured dredged material samples as compared to the coarse-grained marginal soils. Elemental analysis of the plant samples showed that, with the possible exception of boron in Alabama dredged material, none of the elemental concentrations were high enough to be toxic to plants. Zinc and copper contents of plants fell within the normal ranges expected. Nickel and cadmium contents were above the normal ranges expected in plants.

It is concluded that the dredged material used in this study would be beneficial for increasing agricultural production when mixed with marginal soils. Relationships between uptake and the availability of various soil elements were developed that can be used in setting the ratio of dredged material to marginal soil to be used in the field. Physical and chemical data, along with the plant growth data, were used to develop guidelines for the disposal of dredged material on marginal soils.

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SUMMARY

A possible alternative to the present practice of land disposal of dredged material is the application of this material to marginal or degraded agricultural land with the intention of increasing agricultural production. However, at present very little is known about the effects of such an operation on marginal land. The purpose of this study was to gather basic information about the physical and chemical properties of dredged material as they relate to its agricultural potential and to develop guidelines on the suitability of using dredged material as an amendment for marginal soil.

Samples of dredged material and marginal soils were collected for study from 10 locations in the eastern and central United States. In addition, three productive Minnesota soils were chosen as controls. Samples of the dredged material, marginal soil, and mixtures of the two were physically and chemically analyzed prior to plant growth (greenhouse) experiments with ryegrass and barley.

The dredged material samples had a wide variation in texture ranging from sand to clay. The marginal soils were chosen to represent extreme textural differences from the dredged material.

As compared to normal agricultural soils, the bulk densities of the medium- to fine-textured dredged material samples were low, ranging from 0.67 to 1.24 $g/cm^3$. Bulk densities of the two coarse-textured dredged material samples were similar to those of coarse-textured marginal soils. Addition of fine-textured material to coarse-textured material resulted in a lower bulk density for the mixture.

Water-holding capacities of fine-textured dredged material samples were extremely high when compared to those of similarly textured productive Minnesota soils. The 0.33- and 15-bar percentages for the dredged material-marginal soil mixtures were intermediate between the values of the samples of dredged material and marginal soil alone. The two coarse-textured dredged material samples had very low water retention values. Adding coarse-textured dredged material to fine-textured marginal soil resulted in water retention values approximating those of the productive Minnesota soils.

Multiple regression relationships were developed which can be used for predicting soil water retention characteristics of dredged material, marginal soil, and their mixtures by considering particle size, organic mater content, and bulk density.

In general, the chemical properties of the dredged material were not greatly different from the chemical properties of the productive Minnesota soils used in this study. Some of the dredged material samples had relatively high organic matter and nitrogen contents and were usually high in total sulfur and total phosphorus. Only two dredged material samples were higher than expected in soluble salts and exchangeable sodium. Extractable zinc, copper, nickel, and cadmium were relatively high in three of the dredged material samples.

Because of high sulfur content of some of the dredged material samples and the resultant reduction in pH upon drying, large amounts of lime were needed for adequate plant growth.

The oil and grease content of the dredged material samples was greater than that of either the marginal soils or productive Minnesota

soils. The high oil and grease content of a few samples made them slower wetting than most soils but did not appear to affect yield.

Analysis of X-ray diffraction patterns for the dredged material showed that the clay fractions of three dredged material samples contained crystalline minerals which are probably similar to those found in the upland soils from which the dredged material originated. The clay fractions of all other dredged material samples appeared amorphous in nature. The apparent amorphous nature of the clay fractions of many of the dredged material samples partially explains the high water sorption capacity and high loading pressure required for compression.

The plant yields in the greenhouse were greater for the eight fine-textured dredged material samples than for the marginal soils. When dredged material was mixed with marginal soil, plant yields were intermediate between yields for either dredged material or marginal soil.

Elemental analyses of the plant samples showed that, with the possible exception of boron in the Alabama dredged material, none of the elemental concentrations were high enough to be toxic to plants. Zinc and copper contents of the plants fell within the tolerance ranges, while nickel and cadmium contents were above the tolerance ranges expected in plants.

Dredged material can be used for increasing agricultural production when mixed with marginal agricultural soils. However, caution should be exercised in using dredged material with higher than normal concentrations of heavy metal.

# PREFACE

This study was conducted as part of the Corps of Engineers' Dredged Material Research Program (DMRP). The DMRP was sponsored by the Office, Chief of Engineers, U. S. Army, and was administered by the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss.

The study was conducted during the period April 1976-December 1977 by Dr. W. E. Larson, Dr. S. C. Gupta, Dr. R. G. Gast, Dr. R. H. Dowdy, and Ms. Sherry M. Combs. At the time of the study, Dr. Larson and Dr. Dowdy were employees of the Science and Education Administration--Federal Research, U. S. Department of Agriculture, and Dr. Gupta, Dr. Gast, and Ms. Combs were employees of the University of Minnesota. All of the work was done in the facilities of the University of Minnesota Institute of Agriculture.

Appreciation is expressed to a number of students, technicians, and secretaries for help during the conduct of the investigation.

Mr. Charles A. Carlson of WES was responsible for collection of the dredged material samples and, along with Dr. Gupta, for collection of the soil samples. His help is appreciated.

The contract was managed by Dr. Eugene R. Perrier of the Environmental Laboratory (EL), WES. The report was prepared under the general supervision of the Manager of the Productive Uses Project (PUP), Mr. Thomas R. Patin. MAJ Robert M. Meccia, CE, was Manager of PUP during the research phase of the project. Dr. John Harrison was Chief of EL.

During the study and preparation of this report, COL J. L. Cannon, CE, was Director of WES. Mr. F. R. Brown was Technical Director.

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# THE AGRICULTURAL VALUE OF DREDGED MATERIAL

## PART I: INTRODUCTION

Navigable waterways of the United States have played a vital role through the years in the economic growth of this Nation. The responsibility for keeping these waterways open and safe is assigned to the U.S. Army Corps of Engineers. Annually this involves the removal and disposal of about 270 million cubic metres of dredged material.

Economic disposal of dredged material without adverse environmental impact is a major problem, especially in the coastal and Great Lakes areas where shipping is the major conveyance for heavy industry. The environmental problems of dredged material disposal range from disturbance of aquatic ecosystems with open-water disposal to contamination of groundwater with on-land disposal. In recent years, legislation has limited deepwater disposal and has forced the increased use of other alternatives.

A highly attractive alternative for disposal of dredged sediments is to use these materials beneficially to amend marginal lands for agricultural pruposes. Marginal agricultural lands are those which are not intensively farmed because of inherent limitations. These limitations include poorly drained, sandy, or clayey soil; soil in poor physical condition; and, in some instances, soil with chemical shortcomings. Soil may also be low in productivity because of a high water table or frequency of flooding. There are millions of hectares of agricultural marginal lands conventiently located near waterways. They are usually formed from alluvial

**sediments of a much earlier time. Many marginal soils can be amended for increased crop production by mixing with a suitable dredged material. In many cases, mixing of dredged material and marginal soils for better growth of plants would also improve the environment through reduced wind and water erosion.**

About 16 million hectares of cropland occur in the Unites States that could benefit measurably from a greater depth of soil (USDA, 1967). Potentially much of this land could benefit from applications of medium-textured dredged material to deepen the soil material. Included in this 16 million hectares are classes IIS, IIIS, and IVS. Subclass S includes soils with limiting factors such as shallowness, stoniness, low moisture-holding capacity, low fertility difficult to correct, and salinity or sodium. Economic and other considerations will probably preclude use of dredged material on much of this land. However, it can be concluded that ample land exists which might be improved by application of selected dredged material.

## PART II: OBJECTIVES

### Primary Objectives

Primary objectives were to collect and analyze data for use in developing guidelines for the suitability of uncontaminated dredged material for crop production when used alone or as an amendment for marginal soil.

### Specific Objectives

Specific objectives of this study were to:

a. Characterize the physical and chemical properties of selected dredged material and marginal soils.

b. Determine the dry matter production of agricultural crops when grown on dredged material, marginal soils, and their mixtures in a greenhouse study.

c. Perform a plant nutrient analysis to establish the relationships between yield and nutrient uptake for plants grown in the greenhouse in the dredged material and marginal soil treatments.

d. Determine the heavy metal uptake by plants grown in the greenhouse and the heavy metal content of the dredged material and marginal soil treatments for comparison with hazard and tolerance levels.

e. Develop specific recommendations as to the usefulness of adding dredged material to improve marginal soil for agricultural production.

## PART III: LITERATURE REVIEW

### Dredged Material and Soil Studies

Few specific references concerning the characteristics of dredged material and mixtures with soil exist in the literature. However, some work has been reported on similar problems in the areas of marginal soil, turf management, and application of sewage waste to land. The following literature review includes discussion of pertinent work on the effects of dredged material on soil properties and plant production.

Characteristics of sediments accumulated in navigable waterways depend to a large extent on:

- a. Types of soil particles that become suspended in runoff and any materials that have been sorbed by these particles.
- b. Type and extent of industrial development.
- c. Population density.

Dredged material is composed predominantly of mineral particles ranging in size from coarse sand to fine clay and can have an extremely mixed mineralogy (Lee, Engler, and Mahloch 1976). Dredged material deposits within one disposal site can vary from well-ordered sand to pure clay. In addition to soil, dredged material may contain other solids such as rock, wood, pieces of metal, glass, and other debris. Contamination of these sediments in the form of sewage material, elevated concentration of heavy metals, a vast array of chlorinated hydrocarbons, oil and grease, and other organics reflects the influences of population and industry in the area.

Two studies (Gold 1971, Mudroch 1974) have dealt with the potential use of dredged material for production of agricultural crops. Gold studied the growth of several crops, e.g., sweet corn, green peppers, winter wheat, snap beans sudan grass, and spring oats, on mixtures of dredged material and soil, both in the greenhouse and in the field. Mudroch investigated the suitability of dredged material for growing tomatoes and corn in a greenhouse environment.

In a related study, Jewell (1975) analyzed the dredged material from Olcott Harbor, N.Y., and its impact on agricultural land. He suggested that the proportion of dredged material to soil should be based upon the chemical composition of both such that the concentration of any element would not reach a critical level in the final mixture.

Samples from the Chicago District described by Boyd et al. (1972) showed that dredged material can vary widely in organic matter content. Included in the organic fraction of dredged material can be petroleum products, persistent organics, pesticides, and herbicides.

## Soil Physical Properties

### Bulk and particle density

The bulk density of a material gives an indication of the size and arrangement of soil particles, whereas particle density reflects the nature of the particles comprising a given material. Bulk density is a weight measurement by which the entire soil volume is taken into consideration. It is needed for converting water percentage by weight to water content by volume and for estimating the weight of a volume of material too large to weigh conveniently. Free, Lamb, and Carleton (1947),

Klute and Jacob (1949), and Adams (1973) have shown that addition of organic matter to soil reduces its bulk density. Stewart, Adams, and Abdulla (1970) developed a mathematical relationship to predict the effect on bulk density of adding organic matter to soil. Curtis and Post (1964) found a strong ($R = 0.96$) curvilinear relationship between the level of organic matter and the bulk density in the acid-till forest soils of Vermont which had organic matter contents as high as 88 percent by weight. Gupta, Dowdy, and Larson (1977) used a linear relationship to describe the reduction in bulk density of Hubbard sand with the addition of sewage sludge. However, organic matter content as a result of sewage sludge addition was less than 6 percent by weight in their experiment.

Mudroch (1974) reported a range in bulk density of 0.97 to 1.41 $g/cm^3$ for dredged material obtained from several different harbors and lakes in Canada. Particle densities measured on the same samples varied from 2.43 to 2.66 $g/cm^3$. These low densities were attributed to high organic and clay contents in the dredged material. Richards et al. (1964) measured reductions in bulk density from 1.36 $g/cm^3$ to 1.09 and 0.79 $g/cm^3$ on the addition of 30 to 60 percent by weight of peat to a clay loam soil. From the regression analysis of their data, Shykewich and Zawarich (1965) noted that each unit weight increase of organic matter decreased bulk density 15 times as much as that of clay and 4 times as much as that of either fine sand or silt.

## Particle size distribution

Textural properties help determine not only the nutrient-supplying ability of the soil solids, but also the supply of water and

air which is so important to plant life. The dredged material and marginal soils have a wide variation in texture ranging from sand to clay. The particle size distribution was characterized by using the U.S. Department of Agriculture (USDA) textural classification chart (see Figure 31). The USDA has classified and mapped most of the agricultural areas in the United States. This method for naming soils emphasizes a basic property of a soil which to an appreciable extent determines the agricultural economic value of an area. Most agricultural soils of economic importance are some type of loam.

Soil water retention

Water retention characteristics of soil describe the energy relation of soil to water, which in turn can be used to determine the availability of water to plants. This property describes the moisture storing capacity of a soil and is strongly influenced by the arrangement of the solid components of soil and the quantity of fine particles and organic matter.

Several researchers (Stauffer 1936; Russell, Klute, and Jacob 1952; Jamison 1958; and Salter and Haworth 1961) have reported the effect of organic matter on water retention characteristics of soil. Changes in soil water retention characteristics on organic matter addition could be due to:

a. Decreased bulk density and increased total porosity.

b. Change in the aggregate size distribution.

c. Increased adsorptive capacity of the soil.

Bouyoucos (1939) observed an increase in the water-holding capacity (moisture equivalency) and the available water (moisture equivalency minus wilting point) in soils, ranging from sands to clays, with the addition of organic

matter. Biswas and Khosla (1971) also observed a similar increase in the soil-water retention characteristics and hydraulic conductivity of soils to which farmyard manure had been applied over a 20-year period.

Lunt (1959) showed that noncapillary pore space increased by 5 percent after application of Torrington dried sludge to Cheshire loam soil. During this study similar increases were found in the water content at field capacity, i.e., the soil water content 48 hours after a heavy rain. In studying a silt loam soil after applications totaling 327 metric tons/ha of municipal compost, Mays et al. (1973) found increases in water content ranging from 11 to 15 percent corresponding to the percent water at 0.33 bar suction. However, Morachan et al. (1972) did not find a significant increase in soil water retention characteristics after 14 annual applications of 16 metric tons/ha of shredded corn stalks.

Gold (1971) studied the effect of adding dredged material to three coarse-textured soils and measured an increase in soil water retention at every suction. He attributed these increases to the organic matter content resulting from the addition of dredged material to the three soils.

Kivisaari (1971) found a strong relationship between the percentage of clay and the soil water content at the 15 bars soil water retention. Zawadski (1970) reported that the soil water retention values at 0.1 bar increased sharply with an increase in the silt and clay fraction. From tests of mixing peat and sand, Juncker and Madison (1967) showed that changes in bulk density and the difference between the soil water percentage at saturation and 15 bars (maximum water-holding capacity) were as follows:

| Material | Bulk Density $g/cm^3$ | Maximum Water-holding Capacity $cm^3/cm^3$ |
|---|---|---|
| 100% peat | 0.12 | 0.80 |
| 75% peat<br>25% sand | 0.51 | 0.71 |
| 50% peat<br>50% sand | 0.92 | 0.60 |
| 25% peat<br>75% sand | 1.32 | 0.51 |
| 100% sand | 1.56 | 0.44 |

Available water capacity

The available water capacity of a field soil is defined as the amount of water a crop can remove from the soil before its yield is seriously affected by drought. It is a soil water characteristic which suggests the range of soil water retention available for plant growth. This concept was put forward by Veihmeyer (1927), who defined available water capacity as the amount of water held by a soil between the field capacity of a soil and the permanent wilting point of a plant. For most soils, water contents measured at the 0.33-bar soil water retention have been defined as the moisture content at field capacity, while soil water contents corresponding to 15 bars have been defined as permanent wilting point of plants. Based on statistical analysis, Petersen, Cunningham, and Matelski (1968) estimated that the available water capacity was negatively correlated with sand and clay content and positively correlated with silt content for most soils in Pennsylvania. The desirable available water capacity for crop production is given in Table 24.

Hydraulic conductivity

The hydraulic conductivity of a soil material expresses the ease with which water will move or pass through it. The hydraulic conductivity is determined by a number of factors; however, the size of the soil pores and the magnitude of the soil water retention are the most important. In general, clay materials have low hydraulic conductivities compared to sands. Any alteration of the soil structure, i.e., the arrangement of solid components, will affect the hydraulic conductivity. Densen, Shindala, and Fenn (1968) studied the effect of the addition of clay on the hydraulic conductivity of sand and estimated that additions of montmorillonitic clays in amounts greater than 3 percent by weight reduced the permeability of pure sand by 100 percent, whereas the addition of kaolinitic clay in amounts greater than 16 percent by weight reduced the hydraulic conductivity of sand to nearly zero. Richards et al. (1964) observed a sevenfold increase in hydraulic conductivity after the addition of 60 percent peat to a clay loam soil. O'Neal (1949) presented the following hydraulic conductivity classification:

| Hydraulic Conductivity cm/hr | Class | Approximate Texture |
|---|---|---|
| 0.125 | Very slow | Clay |
| 0.125 - 0.5 | Slow | Silty clay |
| 0.5 - 2.0 | Moderately slow | Clay loam, silty clay loam, sandy clay |
| 2.0 - 6.25 | Moderate | Silt loam, silt |
| 6.25 - 12.5 | Moderately rapid | Loam |
| 12.5 - 25.0 | Rapid | Sandy loam, sandy clay loam, loamy sand |
| 25.0 - | Very rapid | Sand |

He concluded that the hydraulic conductivity of a soil could be characterized by knowing the soil structure, direction of easiest natural fracture, size and number of visible pores, and soil texture.

Coefficient of linear extensibility (COLE)

The coefficient of linear extensibility (COLE) is defined as the fractional change in uniaxial length (Grossman et al. 1968). COLE is an index that describes swelling-shrinking potential of soils. Understanding of such phenomenon is important to predict the behavior of soils for a variety of agricultural and engineering uses. Soil volume changes caused by gain of moisture will decrease the proportion of large pores and thus result in lower infiltration. An excessive shrinkage will result in large cracks and thus greater loss of water from deeper depths by evaporation. On the other hand, large cracks can be advantageous in conducting water to deeper depths and thus help in moisture storage and reducing runoff. Excessive swelling and shrinking is also hazardous to farm buildings and structures. Anderson, Fadul, and O'Connor (1973) studied the relationsnip between COLE and other soil parameters for 16 samples selected from the soil horizon. COLE was highly correlated with the percentage of clay and the percentage of exchangeable sodium.

Schafer and Singer (1976) suggested the following limits for the shrink-swell hazards based on the COLE value:

| COLE | Shrink-swell Hazard |
|---|---|
| 0.00 - 0.03 | Slight |
| 0.03 - 0.06 | Moderate |
| 0.06 - 0.06 | Severe |
| $>$ 0.09 | Very severe |

For most soils, COLE is less than 0.03. Franzmeier and Ross (1968) reported that for soil high in montmorillonitic clay, COLE ranged from 0.03 to 0.18, depending on the amount of clay and the soil structure.

## Soil Chemical Properties

### Nutrient characterization

The chemical analysis of a dredged material should provide data to determine the nutrient availability and to establish recommended fertilizer applications for agricultural production. The nutrient content of dredged material varies widely. The clay and organic matter of dredged material determine its sorption capacity for ammonium nitrogen, potassium, metalic cations, heavy metals, and organic compounds (pesticides, herbicides, etc.). The capacity of soil particulates to adsorb nutrients which become available for plant growth is called the cation exchange capacity. It is expressed in units of milliequivalents per 100 grams of material, i.e., 1 milligram of hydrogen (or its equivalent) to 100,000 milligrams of clay equals 10 mg/l equals 1 meq/100 g. Adsorbed or sorbed nutrients are readily available to higher plants and easily find their way into the soil solution. Toth and Ott (1970) found that the cation exchange capacity of sediments from six major waterways along the East Coast varied from 7 to 100 meq/100 g. They concluded that 80 percent of the cation exchange capacity in these samples was due to organic matter. Brannon et al. (1976) found that the dredged material taken from Mobile Bay, Ala., had cation exchange capacity values ranging from 41 to 58 meq/100 g.

Research studies demonstrate that the total nitrogen content of some fine-textured dredged material can range from 200 to 3700 ppm (Brannon et al. 1976, Chen et al. 1975, Federal Water Pollution Control Commission 1969, Lee et al. 1976, Mudroch and Zeman 1975, and Poon and Sheih 1976). According to these studies, the most predominant form of nitrogen other than in organic sediments is ammonium nitrogen. Organic

nitrogen predominates in organically enriched sediments although ammonium concentration can be high.

In most sediments, phosphorus occurs as a phosphate-solids complex (Upchurch, Edzwald, and O'Melia 1974). Total phosphorus has been reported to vary from 450 to 3600 ppm, while soluble phosphorus varies only from 0.8 to 8.8 ppm (Federal Water Pollution Control Commission 1969, Mudroch and Zeman 1975, Poon and Sheih 1976).

Exchangeable potassium can vary from 150 to 1050 ppm as found in dredged material along the East Coast and in the Lower Great Lakes Region (Toth and Ott 1970, Mudroch and Zeman 1975). Toth and Ott's studies of dredged material showed exchangeable sodium to vary from 0.1 to 32.9 meq/100 g, calcium from 1.0 to 10.7 meq/100 g, and magnesium from 0.5 to 25.0 meq/100 g.

Concentrations of total sulfide in anaerobic dredged material ranged from 0 to 5390 µg/g in sediments from marine, estuarine, and freshwater sources (Brannon et al. 1976, Chen et al. 1975). Free sulfide was measured in some samples at concentrations of 200 mg/g. Fleming and Alexander (1960) reported that sediments in a South Carolina tidal marsh developed high acidity when drained and allowed to dry. These sediments contained up to 55,000 µg/g of total sulfur when these sediments were drained and sulfides were oxidized to sulfate with a resulting decrease in pH from 6.4 to 2.0.

Heavy metals

In general, dredged sediments do not contain excessive amounts of heavy metals. A number of sediments from rivers, harbors, and bays throughout the United States and Canada contain heavy metals in varying

concentrations (Brannon et al. 1976; Chen et al. 1975; Federal Water Pollution Control Commission 1969; Holmes, Salde, and McLerran 1974; Mudroch and Zeman 1975; Oliver 1973; Windom 1973; and Poon and Sheih 1976). Some of the major sources of metals that contribute to abnormally elevated concentrations of metals in dredged material are discharges from sewage and industry, urban and highway runoff waters, and snow removal. Wastes containing significant amounts of copper, chromium, zinc, nickel, and cadmium have found their way into some sediments (Wentink and Etzel 1972).

The potential of a heavy metal to become a contaminant depends greatly on its form and availability rather than on its total concentration within a dredged sediment. Heavy metals may be fixed in a slightly soluble form in dredged materials containing sulfide. The land application of dry oxidized dredged material may increase the solubility of heavy metal sulfides. However, under oxidized conditions the pH and heavy metal hydroxyl and oxide formations become important factors, and sulfur no longer governs the solubility and availabiltiy fo heavy metals.

Liming

Lime is applied to soils to adjust the pH within a range of 6 to 7 so that plant nutrients are readily available. A soil pH below 4.0 indicates the presence of free acids resulting from oxidation of sulfides; a pH below 5.5 suggests the presence of exchangeable aluminum; and a pH from 7.8 to 8.2 indicates the accumulation of calcium carbonate (McLean 1975). At an extremely low pH, hydrogen sulfide, various types of aluminum, and manganese ions are often present in quantities toxic to plants. Above pH 7, manganese, zinc, iron, etc., may be insoluble to plants.

## Electrical conductivity and salt tolerance of plants

Electrical or specific conductivity of an extract gives an indication of the total concentration of soluble salts in soil. The term "soluble salts" refers to the inorganic soil constituents that are soluble in water. Excess soluble salts not only limit the availability of water to plants but also restrict their growth.

Differences among plants make it difficult to generalize regarding the toxicity to plants of various salts or ions. Plant tolerances to excessive concentrations of ions are related to specific selectivity of ion absorption and nutrient requirements of the plant. A general guide of crop responses to salinity under average conditions is given in Table 1.

## DTPA analysis

Lee et al. (1978) evaluated four soil extraction procedures (water soluble, exchangeable, dilute acid extraction, and diethylenetriamine pentaacetic acid (DTPA) extraction) to determine the best method to measure heavy metals in soil materials to compare with plant uptake of heavy metals. Their studies indicated that the DTPA extraction method provided the best comparisons.

## Clay mineralogy

In an assessment of the agricultural value of dredged material, its clay mineralogy plays an important role in both the soil physical and soil chemical behavior of soil-dredged mixtures (Kunze et al. 1968). The important physical properties of water retention and hydraulic conductivity are fundamentally controlled by mineralogical composition. Tillage practices are dependent upon the forces which hold clay particles

Table 1

Crop Recommendations for Saline Soils (USDA, 1953)

| Electrical conductivity of saturated extract | Plant growth conditions |
|---|---|
| mmho/cm | |
| $<2$ | Salinity effects largely negligible |
| 2- 4 | Yields of sensitive crops may be restricted |
| 4- 8 | Yields of many crops will be restricted |
| 8-16 | Only tolerant crops yield satisfactory |
| $>16$ | Only very tolerant crops yield satisfactorily |

together as well as the degree of clay hydration. The chemical properties of soils are controlled by the types and amounts of clay materials present. Soil pH control and the availability, or lack thereof, of most plant nutrients are functions of the cation exchange capacity (CEC) of clay materials. Hence, one can use mineralogical data to predict and interpret the physical and chemical behavior of soil-dredged mixtures.

## Plant Growth Studies

Lower bulk densities of soil material resulting from the addition of organic matter in dredged material increase the soil volume and thus help root growth. Donahue, Schicluna, and Robertson (1971) have shown that normal root growth is severely restricted at bulk densities greater than 1.4 and 1.6 g/cm$^3$ in fine- and coarse-textured materials, respectively. Mudroch (1974) noted that growth of seedlings on dredged material was directly proportional to the total porosity of the sediments.

Changes in hydraulic conductivity by adding organic matter to soil can affect water entry, drainage, evaporation, and movement of water to roots. These changes can have a profound impact on plant growth. According to Lee et al. (1976), the acidity of dredged material containing high levels of nonvolatile sulfides can have a serious effect on plant growth unless the dredged material is limed or mixed with an alkaline soil.

Gold (1971) concluded that the addition of 448 to 672 metric tons/ha of dredged material to sandy soil increased yields from 40 to 100 percent or more. Applications of dredged material to loam and silty

soils had no adverse effect on yield when the mixtures were properly limed and fertilized. No major changes were reported in the elemental composition of plants grown on mixtures of soil and dredged material, even though dredged material had a greater heavy metal content. The exception was the content of zinc, which consistently increased. There were no reported concentrations of mercury, lead, arsenic, or cadmium in the plants, although all of these metals were present in significant amounts in the dredged material.

Mudroch's 1974 greenhouse study of the suitability of dredged material demonstrated that dredged material can differ; i.e., that yields were highest for tomatoes grown on Humber Bay dredged material followed by those grown on dredged material from Hamilton Harbor and the Detroit River. The following maximum concentrations were determined for tomato fruit grown in Humber Bay sediments:

| Element | Concentration mg/kg |
|---|---|
| Potassium | 37,000 |
| Magnesium | 2,100 |
| Calcium | 1,750 |
| Zinc | 40 |
| Sulfur | 30 |
| Copper | 23 |
| Lead | 12 |
| Cobalt | 7 |
| Cadmium | 2 |

Arsenic, molybdenum, manganese, chromium, nickel, and mercury were below the level of detection.

## PART IV: EXPERIMENTAL DESIGN

### Site Selection

Sampling sites were selected by the Corps of Engineers based on minimal industrial contamination and the magnitude of the dredged material disposal problem in the area. With the help of the U.S. Soil Conservation Service, marginal soils, suitable for the addition of dredged material, were selected within a radius of 15 to 20 km from the dredged material disposal areas. A map showing the general location of each sampling site is presented in Figure 1. The locations of the dredged material sampling sites and information relating to the marginal soils are given in Table 2.

#### Geographical locations

Dredged material samples representing a wide range of dredged material were collected from 10 geographical locations in the eastern and central United States. A description of each location is given below:

a. Mobile, Ala. The dredged material samples were taken from the Blakely Island north disposal area. The marginal soil, identified as Troup loamy sand, was from a pine woodland area 18 km northwest of Blakely Island. This tract has never been cultivated and had a sparse forest cover.

b. New Haven, Conn. The disposal area was triangular in shape and bounded by the West River, Interstate Highway 95, and a railroad bed. The area had previously been covered with a dense stand of dry Phragmites which was burned a few days prior to sampling. Samples of the marginal soil were taken from an abandoned vineyard covered with grasses, weeds, and poor grape vines, located in North Haven. The soil was identified as Penwood loamy sand.

c. Chain O'Lakes, Ill. The dredged material was sampled from the diked disposal area located south of the channel connecting Grass Lake to Fox Lake at the Cubs Cove Marina. The marginal soil, identified as a Boyer loamy sand, was sampled from a field about 3 km north of Island Lake and 3 km west of U.S. Highway 12.

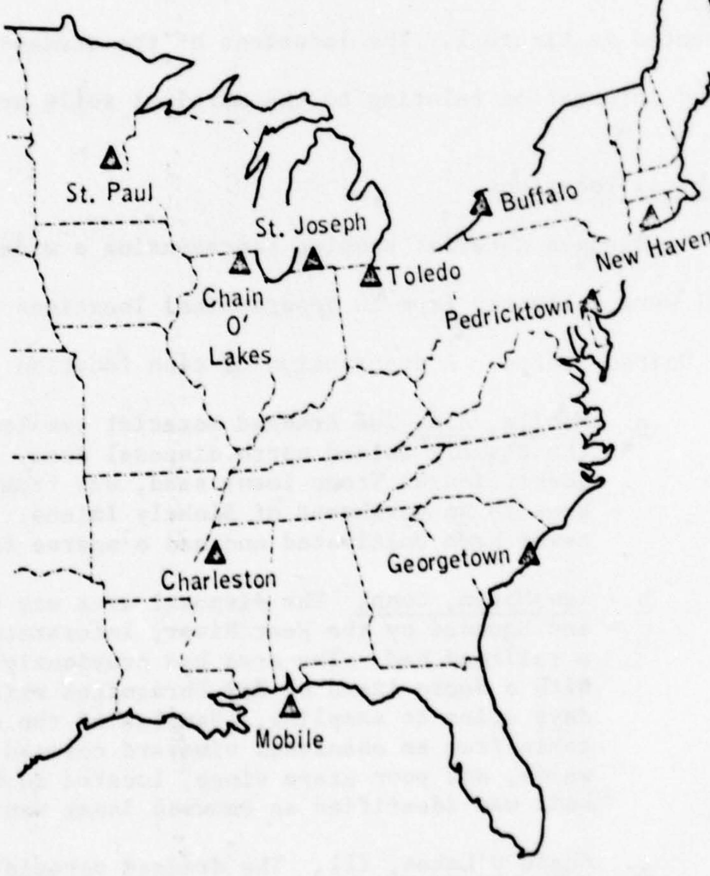


Figure 1. Map showing locations from which dredged material and marginal soils were collected

Table 2

Geographical Locations of the Dredged Material Sampling Sites and Classifications of Corresponding Marginal Soils

| Geographical location | Waterway | Marginal soil | Dredged material texture |
|---|---|---|---|
| Mobile, Ala. | Mobile River | Troup loamy sand | Clay |
| New Haven, Conn. | West River | Penwood loamy sand | Silt loam |
| Chain O'Lakes, Ill. | Fox Lake | Boyer loamy sand | Silt loam |
| St. Joseph, Mich. | St. Joseph River | Spinks loamy sand | Sandy loam |
| St. Paul, Minn. | Mississippi River | Bremer silty clay | Sand |
| Charleston, Miss. | Mississippi River | Forestdale silty clay loam | Sand |
| Pedricktown, N.J. | Delaware River | Evesboro sand | Silty clay loam |
| Buffalo, N.Y. | Buffalo River | Elnora fine sandy loam | Silt loam |
| Toledo, Ohio | Maumee River | Spinks fine sand | Silty clay |
| Georgetown, S.C. | Winyah Bay | Wando sand | Clay |

d. St. Joseph, Mich. The dredged material was an organic clay silt with some sand which was obtained adjacent to the U.S. Coast Guard Station. The marginal soil was sampled from a field approximately 8 km east of the Coast Guard Station and north of Territorial Road. The soil was identified as Spinks loamy sand.

e. St. Paul, Minn. The dredged material samples were taken from the Corps of Engineers' demonstration plots on Grey Cloud Island, 24 km southeast of St. Paul adjacent to the Mississippi River. The marginal soil, identified as Bremer silty clay, was collected from a wooded area 1.6 km southwest of the Chicago-Milwaukee railroad line and 3 km north of U.S. Highway 12, near Red Wing, Minnesota.

f. Charleston, Miss. The dredged material disposal area was 3 km northeast of the State Highway 32 bridge over the Tallahatchie River. The marginal soil samples, Forestdale silty clay loam, were taken from a field 300 m southwest of the disposal area.

g. Pedricktown, N.J. The dredged material sampling site was the Pedricktown south disposal area in the abandoned Delaware Ordinance Depot. This area of dredged material has a depth of more than 4 m, of which the maximum depth of inspection (1 m) was fine organic silt. Native vegetation at the sampling location consisted of Phragmites, Reed canarygrass, giant ragweed, black willow, and elderberry. The marginal soil samples, identified as Evesboro sand, were taken from a field located within the ordinance depot. Vegetative cover included broomsedge and grasses with scattered trees.

h. Buffalo, N.Y. The dredged material was obtained from the disposal area south of the small craft harbor. The marginal soil, Elnora fine sandy loam, was sampled on state-owned land 20 km northeast of the disposal site and 8 km east of the mouth of the Erie Canal at Tanawanda. The area was covered by brush and woods.

i. Toledo, Ohio The dredged material was taken from a disposal area, Penn No. 7, about 3 km southwest of the Corps office. The sampling area was covered with willows, poplars, and weeds. The marginal soil samples, identified as Spinks fine sand, were collected from a wooded area in the Lucas County Industrial Park, 25 km west of the disposal area and 3 km north of the Toledo express airport. The vegetation was scattered trees with a shrub and grass undergrowth.

j. Georgetown, S.C. The disposal area sampling site was located on an island about 1.6 km east of Georgetown and north of U.S. Highway 17. The marginal soil sampling site was 3 km southwest of the city. The soil was identified as Wando sand.

Sample collection procedure

All the samples were collected in plastic bags and shipped to St. Paul in 80- to 200-litre plastic-lined steel drums. On an average, each sample weighed 350 kg on a dry weight basis. Dredged material known to be contaminated with large amounts of toxic chemicals was not included. The marginal soils were selected because of their low productivity for plant growth. The soils were not being used for agricultural production and were not considered suitable for this purpose.

Three productive soils were chosen from the St. Paul, Minn., area to serve as controls for the greenhouse plant growth study. These soils were identified as Nicollet loam, Waukegan sandy loam, and Bold* loam.

## Greenhouse Experiment

Material preparation

The dredged material and marginal soil samples were placed on plastic sheets and air-dried. Fans and frequent turning of the samples hastened drying.

After drying, the samples were ground in a hammer mill and passed through a 2.00-mm screen. The samples were then mixed in a modified cement mixer lined with epoxy and equipped with a lid. Particle size analysis was used to confirm the adequacy of mixing. Table 3 gives the particle size analyses of six random samples taken after mixing for a coarse-textured Connecticut soil and a fine-textured New Jersey dredged material. Differences in the particle size distribution were minimal among the six random samples of both materials; thus, the mixing was adequate and the samples appeared homogeneous. Dredged material and marginal soil

* Also called "Port Byron," "Port B.," and "P. Byron" elsewhere in this report.

Table 3

Particle Size Analysis to Test Adequacy of Dredged Material and Soil Mixing

| Sample No. | Sand (mm) | | | | | | | | Silt | | | Clay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2-1 | 1-0.5 | .5-.42 | .42-.25 | .25-.1 | .1-.074 | .074-.05 | Total | Coarse | Fine | Total | <2μ |
| | Percent | | | | | | | | | | | |
| **Connecticut soil** | | | | | | | | | | | | |
| 1 | 6.9 | 23.4 | 8.9 | 27.5 | 14.5 | 5.9 | 2.3 | 89.2 | 0.9 | 5.5 | 6.4 | 4.5 |
| 2 | 6.5 | 23.8 | 10.2 | 27.1 | 16.6 | 3.4 | 2.2 | 89.5 | 1.1 | 4.3 | 5.4 | 5.2 |
| 3 | 6.1 | 22.9 | 9.5 | 27.7 | 9.1 | 11.9 | 2.3 | 89.4 | 1.1 | 4.4 | 5.5 | 5.2 |
| 4 | 5.9 | 23.4 | 9.8 | 27.9 | 12.7 | 8.0 | 2.4 | 89.9 | 1.3 | 3.9 | 5.2 | 5.0 |
| 5 | 5.9 | 24.6 | 9.7 | 27.5 | 16.2 | 3.8 | 2.2 | 89.7 | 1.0 | 4.8 | 5.7 | 4.7 |
| 6 | 7.1 | 24.5 | 10.3 | 26.7 | 13.6 | 5.7 | 2.1 | 89.9 | 1.6 | 4.4 | 5.9 | 4.3 |
| Average | 6.4 | 23.8 | 9.7 | 27.4 | 13.8 | 6.5 | 2.3 | 89.6 | 1.2 | 4.6 | 5.7 | 4.8 |
| **New Jersey dredged material** | | | | | | | | | | | | |
| 1 | 0.5 | 0.6 | 0.1 | 0.5 | 3.2 | 3.8 | 9.8 | 18.5 | 10.1 | 40.0 | 50.1 | 32.7 |
| 2 | 0.1 | 0.2 | 0.2 | 1.3 | 2.1 | 3.4 | 13.9 | 21.2 | 8.1 | 38.9 | 47.0 | 33.3 |
| 3 | 0.1 | 0.1 | 0.1 | 0.3 | 2.1 | 3.3 | 9.4 | 15.4 | 11.5 | 41.3 | 52.7 | 32.0 |
| 4 | Not determined | | | | | | | 14.6 | 13.3 | 41.6 | 54.9 | 30.7 |
| 5 | 0.1 | 0.2 | 0.3 | 0.3 | 2.1 | 3.5 | 14.7 | 21.1 | 9.8 | 37.7 | 47.4 | 31.7 |
| 6 | Not determined | | | | | | | 14.6 | 12.5 | 39.5 | 52.0 | 33.5 |
| Average | 0.2 | 0.3 | 0.2 | 0.6 | 2.4 | 3.5 | 12.0 | 19.2 | 10.9 | 39.8 | 50.8 | 32.3 |

samples were further mixed in various proportions for the laboratory analysis and the greenhouse plant growth studies. The treatments were:

a. Dredged material.

b. 2/3 dredged material to 1/3 marginal soil.

c. 1/3 dredged material to 2/3 marginal soil.

d. Marginal soil.

Samples were then taken from these treatments for physical and chemical analyses.

Based on standard soil test data (Table 12), the treatments were fertilized with recommended amounts (Table 4) of phosphorus ($HPO_4$) and potassium (KCl) fertilizer. Since some of the treatments were low in pH and high in reserve acidity, they were amended with lime ($CaCO_3$) at the rates shown in Table 4. The application rates were based on those recommended by the Soil Testing Laboratory at the University of Minnesota (Table 5). For example, the buffer index of the Alabama dredged material was 5.7 (Table 12). Thus, from Table 5, lime required to raise the pH of the soil water to 5.7 was 19.0 metric tons/ha (Table 4).

Mixing of fertilizers and lime with the samples was done in two steps. The first step involved mixing of fertilizer and lime with 500 g of the sample in a plastic bag. This 500-g subsample was then mixed with the remainder of the sample in the cement mixer.

Straight-wall containers made of white extruded plastic were used for the greenhouse study. Each container was filled with 4500 g of an air-dried, fertilized portion of a treatment. Three sizes of plastic containers (19, 24, 30 cm) were selected because of the differences in the bulk density of the treatments (0.6 to 1.7 $g/cm^3$). Bulk densities.

Table 4

**Phosphorus, Potassium, and Lime Added to the Treatments**

**Prior to Ryegrass and Barley Growth Experiments**

| | | Phosphorus (kg/ha) | Potassium (kg/ha) | Lime (metric tons/ha) |
|---|---|---|---|---|
| Ala. | D.M. | --** | -- | 19.0 |
| | 2/3 D.M. | -- | -- | 19.0 |
| | 1/3 D.M. | -- | -- | 16.8 |
| | Soil | 56 | 190 | 13.4 |
| Conn. | D.M. | -- | 112 | 20.2 |
| | 2/3 D.M. | -- | 101 | 20.2 |
| | 1/3 D.M. | -- | 123 | 20.2 |
| | Soil | -- | 134 | 12.3 |
| Conn.* | D.M. | -- | 112 | 60.5 |
| | 2/3 D.M. | -- | 101 | 60.5 |
| | 1/3 D.M. | -- | 123 | 60.5 |
| Ill. | D.M. | 56 | 129 | -- |
| | 2/3 D.M. | 56 | 123 | -- |
| | 1/3 D.M. | 56 | 129 | -- |
| | Soil | -- | 134 | -- |
| Mich. | D.M. | -- | 62 | -- |
| | 2/3 D.M. | -- | 22 | -- |
| | 1/3 D.M. | -- | 11 | -- |
| | Soil | -- | 11 | -- |
| Minn. | D.M. | -- | -- | -- |
| | 2/3 D.M. | -- | 75 | -- |
| | 1/3 D.M. | -- | -- | -- |
| | Soil | -- | 196 | -- |
| Miss. | D.M. | -- | 190 | -- |
| | 2/3 D.M. | -- | 78 | -- |
| | 1/3 D.M. | -- | -- | 6.7 |
| | Soil | -- | -- | 9.0 |
| N.J. | D.M. | -- | -- | 16.8 |
| | 2/3 D.M. | -- | -- | 16.8 |
| | 1/3 D.M. | -- | -- | 14.6 |
| | Soil | -- | 168 | 12.3 |

* Due to poor growth and low pH, the initial Connecticut dredged material and mixtures were replaced and additional lime added. (3X initial required).

** Dashes indicate adequate amounts.

Table 4 (concluded)

| | | Phosphorus (kg/ha) | Potassium (kg/ha) | Lime (metric tons/ha) |
|---|---|---|---|---|
| N.Y. | D.M. | -- | 129 | -- |
| | 2/3 D.M. | -- | 101 | -- |
| | 1/3 D.M. | -- | 101 | -- |
| | Soil | -- | 118 | 17.9 |
| Ohio | D.M. | -- | -- | -- |
| | 2/3 D.M. | -- | -- | -- |
| | 1/3 D.M. | -- | 56 | -- |
| | Soil | -- | 168 | 15.7 |
| S.C. | D.M. | -- | -- | 20.2 |
| | 2/3 D.M. | -- | -- | 17.9 |
| | 1/3 D.M. | -- | -- | 14.6 |
| | Soil | 56 | 190 | 6.7 |
| Wauk. | | -- | -- | -- |
| Bold | | -- | -- | 14.6 |
| Nicol. | | 56 | 45 | 10.1 |

Table 5

Lime Recommendations for Medium-Textured Soils in Minnesota

| SMP Buffer Index | Lime required to raise soil water pH to 6.5 (metric tons/ha) |
|---|---|
| 6.8 | 6.7 |
| 6.7 | 6.7 |
| 6.6 | 9.0 |
| 6.5 | 10.1 |
| 6.4 | 11.2 |
| 6.3 | 12.3 |
| 6.2 | 13.4 |
| 6.1 | 14.6 |
| 6.0 | 15.7 |
| 5.9 | 16.8 |
| 5.8 | 17.9 |
| 5.7 | 19.0 |
| 5.6 | 20.2 |

were measured after compaction of the materials in the plastic containers. Compaction was accomplished by dropping each container 50 times from a height of 10 to 15 cm. During this process, a Plexiglas lid was used to prevent excessive loss of material from the container. A tensiometer with a ceramic tip 3.0 cm in length by 1.0 cm in diameter (Figure 2) was installed at a depth of 7.5 cm from the surface of the sample (Figure 3) in each of 43 containers, i.e., one for each treatment and location including the three productive Minnesota soils. Samples were then brought to a water content corresponding to 0.1 bar suction as determined in the laboratory and allowed to incubate at room temperature in the greenhouse for about 2 weeks to allow the lime to react and raise the pH. General setup of the greenhouse experiment is shown in Figure 4. Wooden spacers were used to bring the tops of all containers to approximately the same height to eliminate shading because of various size containers.

Plant selection

Barley (Hordeum vulgare L., Larker variety) and annual ryegrass (Lolium multiflorum Lam., Westerwool variety) were selected for the greenhouse study. They were selected because they grow well under relatively low light intensities and fluctuating temperatures often encountered in a greenhouse.

Statistical design

The greenhouse study involved 2 plant species, each replicated 5 times, with 4 treatments of dredged material and marginal soil from 10 locations requiring 400 containers. For treatment control, productive Minnesota soils were replicated 10 times and planted with the same 2

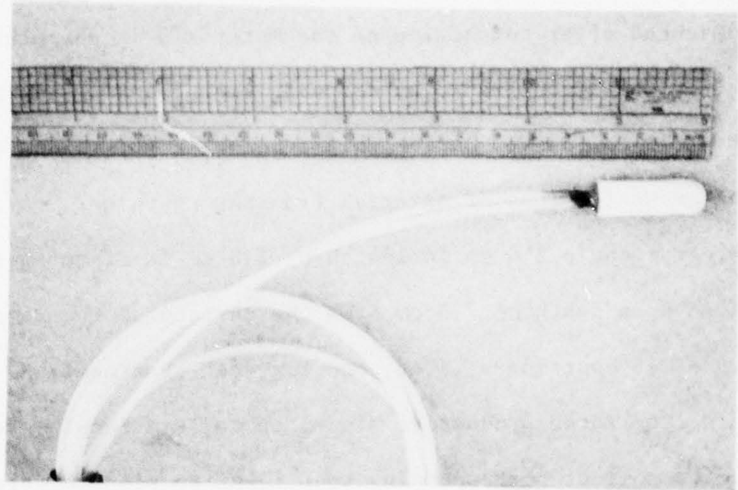

Figure 2. Ceramic tip used in the construction of tensiometer

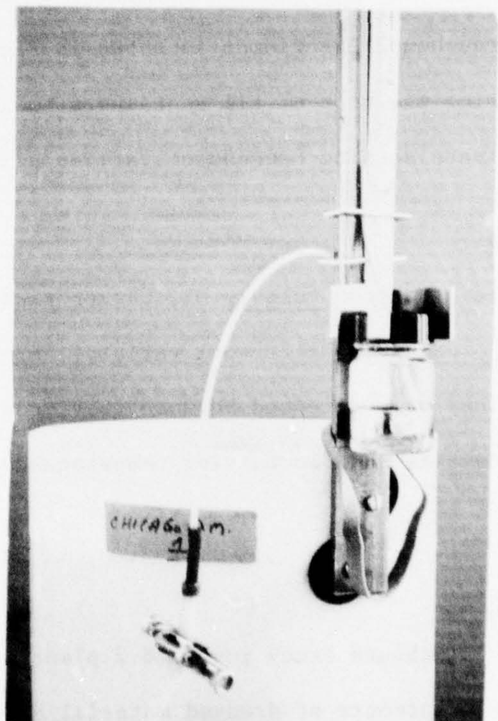


Figure 3. Tensiometer setup in a greenhouse container

Figure 4. General setup of the greenhouse experiment

plant species requiring an additional 60 containers. Thus, the total number of containers used in the study was 460. A split plot experimental design was used with 46 containers for each treatment being randomly distributed in each of 5 split plots for each crop. This technique was selected to minimize the effect of container location within the greenhouse.

Seeding, watering, and fertilizing

Fifteen barley seeds and forty ryegrass seeds were evenly distributed on the surface and covered with air-dried material of the respective sample. The soil surface was kept moist until seed germination by spraying water on the surface using an atomizer. Germination of both crops was good in all materials except for the Connecticut treatments. Tests on small soil samples taken from these treatments showed a pH of about 4.0. Apparently, the recommended amounts of lime were not enough to raise the pH of this material. Therefore, samples of the Connecticut treatments were mixed with three times the quantity of lime recommended by soil tests and new crops of barley and annual ryegrass were seeded. At this time, ryegrass was seeded on one of the productive soils (Waukegan loam) for comparison of growth with the reseeded Connecticut treatments.

Ten days after seeding, the crops were thinned to 10 barley plants and 20 ryegrass plants per container. The plants were regularly brought to a water content corresponding to about 0.1 bar suction as measured by the tensiometers. Each container was weighed on a weekly basis and received a known volume of water every other day to avoid plant water stress.

The application of nitrogen ($NH_4NO_3$) was initiated after 10 days and continued at 1-week intervals at the rate of 55 kg/ha.

Frequent applications of water and nitrogen were planned to lessen the effects of the various plant growth materials.

Harvesting

Crops were harvested when the plants reached the boot stage of growth. The schedules of planting and harvesting of both crops are shown in Table 6. Ryegrass was cut 5 cm from the soil surface, whereas barley was clipped at the soil surface. The leftover portions of individual ryegrass plants were pulled at the end of the third cutting to obtain an accurate count of the plants per container. Plant samples for both ryegrass and barley were dried at 55°C, weighed for dry matter production, and ground for chemical analysis.

Soil sampling

After harvest, three undisturbed 7.6-cm-high by 7.6-cm-diameter cores were taken with a Uhland Sampler from ryegrass containers for bulk density, soil water retention, and hydraulic conductivity measurements. Except for sandy material, clod samples were taken to measure the COLE of the treatments. The remainder of the treatment material in the ryegrass containers was thoroughly hand-mixed, and a 500-g sample was dried, ground, and sieved for soil testing. Two 500-g material samples were also taken from the barley containers and the above procedure was repeated. One of these samples was used for standard soil chemical tests and the other sample for heavy metal analysis.

Table 6

Schedules of Planting and Harvesting Two Crops of

Barley and Three Cuttings of Annual Ryegrass

| Crops/Cuttings | Planting Date | Harvesting Date | Growth Period Days |
|---|---|---|---|
| Barley | | | |
| 1st | 11/26/76 | 1/3/77 | 38 |
| 2nd | 1/13/77 | 2/28/77 | 47 |
| Annual Ryegrass | | | |
| 1st | 11/26/76 | 1/3/77 | 38 |
| 2nd* | | 2/3/77 | 51 |
| 3rd* | | 3/1/77 | 25 |
| 1st+ | 1/12/77 | 2/28/77 | 47 |
| 2nd+ | | 4/1/77 | 31 |
| 3rd+ | | 4/26/77 | 25 |

* Excluding Connecticut dredged material, 2/3 dredged material + 1/3 marginal soil, and 1/3 dredged material + 2/3 marginal soil.

\+ New samples of Connecticut dredged material, 2/3 dredged material + 1/3 marginal soil, and 1/3 dredged material + 2/3 marginal soil and Waukegan soil.

## PART V: LABORATORY ANALYSES

### Physical Methodology

#### Bulk density

Air-dry bulk densities of the treatment material in the plant containers were calculated from the volumes of material **after** compaction. Bulk densities of laboratory and greenhouse cores were determined by coating a known weight of oven-dried clods with wax and measuring the volume by displacement techniques (Blake 1965).

#### Particle size analyses

Particle size analyses were performed by direct sieving of the sand fraction and by the international pipette method for silt and clay (Day 1965). These methods involved the oxidation of organic matter with hydrogen peroxide in a 10-g soil sample, washing the sample free of soluble salts, and then dispersing it in sodium hexametaphosphate. Silt and clay contents were determined by pipetting two 25-ml aliquots at a given depth and time after sedimentation.

Depth and time after sedimentation were calculated by Stoke's law which is based on the settling velocity of particles in water.

#### Core preparation

Soil water retention and hydraulic conductivities were determined in artificially prepared cores in the laboratory. Cores (7.6 cm in diameter by 7.6 cm high) were prepared by compressing a known weight of soil at both ends until the desired bulk density was obtained. Bulk densities of these cores were checked at 1-cm length intervals with a gamma probe. These bulk densities were close to the air-dry bulk densities

obtained in the greenhouse experiment. Cores with significantly deviating bulk densities from the average values were discarded. To test the validity of the packing procedure, data from these cores were checked against sample cores taken from the greenhouse containers.

Soil water retention

Soil water retention values were obtained by desorbing saturated cores at several pressure steps using a pressure plate apparatus (Richards 1965). The prepared cores were saturated overnight from the bottom under a small head of water. Water content at each pressure step was estimated from the volume of outflow between pressure steps, the final water content, and the weight of the oven-dried soil. For less than 2.0 bars pressure, millipore filters were used on the pressure plate apparatus; at higher pressures, ceramic plates were used. More than 24 hours was required to saturate certain samples with a 7-mbar water head due to water repellency caused by the presence of oil and grease. In a few cases, after several days under the 7-mbar head, a small vacuum was necessary to achieve complete saturation. Available water capacity for each treatment was calculated from the difference in water content corresponding to 0.33- and 15-bar suctions.

Hydraulic conductivity

Saturated hydraulic conductivity was determined by the constant head method (Klute 1965). In samples with low saturated hydraulic conductivity, the above method was supplemented with determinations using the falling head method. Five to six measurements were taken on each core. In some samples, the hydraulic conductivity continuously decreased with

time over a period of several days. In these samples, saturated hydraulic conductivity was calculated from the final flow rate.

Unsaturated hydraulic conductivity was calculated from the soil water diffusivity determined from the "one-step" outflow method (Gupta et al. 1974) and the slope of the soil water retention curve. Details of these methods are described by Gupta, Dowdy, and Larson (1977).

### Coefficient of linear extensibility (COLE)

COLE was estimated from the clod samples taken at the end of the greenhouse study. Two to three clods were brought to 0.33 bar water content in the laboratory and their volume measured using the displacement techniques desc~'hed by Blake (1965). Similarly, volumes were measured on three separate clods which had been oven-dried. COLE was calculated from the relationship

$$COLE = \sqrt[3]{\frac{Dd}{Dw}} -1$$

where Dd = oven-dry bulk density, $g/cm^3$, and

Dw = bulk density, $g/cm^3$, at water content corresponding to 0.33 bar suction.

## Chemical Methodology

### Soil elemental analyses

Tests for pH, available phosphorus, available potassium, and extractable sulfur were made in the Soil Testing Laboratory at the University of Minnesota (Fenster et al. 1976) following the procedures shown in Table 7. In addition, further elemental analyses were made in the soil chemistry laboratory using standardized techniques as shown in Table 8.

Table 7

Description of Procedures Used in Soil Testing

Laboratory at the University of Minnesota

| Soil Parameter | Description | Reference |
|---|---|---|
| pH | Determined with a glass electrode pH meter on a 1:1 soil to water suspension. | Peech (1965), Davis (1975), McLean (1975) |
| Liming (Buffer Index) | Determined with a pH meter on intermittently (20 minutes) stirred 1:1 soil to water suspension and SMP buffer solution. | Shoemaker et al. (1961) |
| Soluble Salts | Determined by measuring the electrical conductance of saturation extract with a solu bridge. | USDA, 1953 |
| Extractable Phosphorus | Determined by measuring with an absorption spectrophotometer the intensity of the blue color in the extract (soil plus Bray No. I extractant) when treated successively with ammonium molybdate-hydrochloric acid and ammonium-naphthol-sulfonic acid solution. | Bray and Kurtz (1945) |
| Exchangeable Cations | Determined with a flame emission spectrophotometer on a soil-ammonium acetate extract. | Chapman (1965), Pratt (1965) |
| Extractable Sulfur | Determined turbidimetrically on a soil-monocalcium phosphate solution extract. | Bardsley and Lancaster (1965) |

Table 8

Description of Procedures Used for Chemical Analysis of Soil Samples and Where Indicated for Plants

| Soil and Plant Parameter | Description | Reference |
|---|---|---|
| pH | Measured with a combination glass electrode on a direct-reading Beckman pH meter in a 1:2.5 soil to water suspension. | Peech (1965) |
| Electrical Conductivity | Measured with a conductivity bridge on the above solution. | Bower and Wilcox (1965) |
| Exchangeable Bases | Measured by analyzing INN $H_4$ OAC soil leachate on a Varian Techtron AA Atomic Adsorption Spectrometer. Cations analyzed are calcium, magnesium, sodium, and potassium. | Chapman (1965) |
| Cation Exchange Capacity | Determined by Semimicro distillation of exchangeable ammonium obtained after leaching above sample with acidified 10 percent KCL. | Chapman (1965) |
| Total Nitrogen in Soil and Plant | Determined by titration of ammonia released by Semimicro distillation of samples previously digested with concentrated $H_2SO_4$. | Bremner (1965) |
| Total Sulfur | Determined turbidimetrically with barium salt on a soil-acid ($HNO_3$-$HCLO_4$) digest. | Tabatabia and Bremer (1970) |
| Total Phosphorus | Determined colorimetrically with vandomolybdate on a soil-acid ($HNO_3$-$HCPO_4$) digest. | Tandon, Cescas, and Tyner (1968) |

Plant elemental analyses

Barley and rye plant samples were dried at 70°C then ground in a stainless steel Wiley Mill, and for a specific analysis they were dry-ashed in a furnace for 12 hours at 485°C. Elemental analyses (phosphorus, potassium, calcium, magnesium, aluminum, iron, sodium, maganese, zinc, copper, boron, lead, nickel, chromium, and cadmium) of the digested samples (2N Hcl + ash) were made on a Plasm Emission Spectrograph.

Extractable metals

Extractable metals were determined from an extract of a 1:5 soil solution where the solution was composed of 0.005 mole DTPA (diethylenetriamine pentaacetic acid), 0.01 mole calcium chloride ($CaCl_2$), and 0.1 mole TEA (triethanolamine) as a buffer at pH 7.3 for 24 hours (Lee, et al. 1978). The extracts were analyzed on a Plasm Emission Spectrograph for iron, manganese, lead, mercury, zinc, copper, nickel, and cadmium.

Clay mineral analyses

Preparation of the dredged material for X-ray diffraction included removing the soluble salts and organic matter before separation of the 12-micron fraction. Samples were saturated with potassium, dried at 110°C for 24 hours, and dessicated while duplicate samples were saturated with magnesium, solvated with glycol, and air-dried (Jackson 1969). The slides were analyzed on a diffractometer.

Oil and grease analyses

Dredged material and marginal soil were analyzed by standard methods (American Public Health Association 1971) using hexane as the extractant.

## PART VI: RESULTS AND DISCUSSION

### Characterization of Soil Physical Properties

The physical characteristics determined include texture (particle size distribution), bulk density, moisture retention characteristics, available water capacity, hydraulic conductivity, and COLE. Data for various treatments are given in Table 9.

#### Textural relations

The dredged material samples varied widely in texture ranging from sand to clay. Four of the dredged material samples had clay contents greater than 30 percent, four samples had clay contents from 11 to 30 percent, and two samples had less than 10 percent. The U.S. Department of Agriculture textural classification system was used to classify the treatments, i.e., clay particles vary in diameter from 0.000 to 0.002 mm, silt from 0.002 to 0.05 mm, and sand from 0.05 to 2.0 mm.

The marginal soils were chosen to represent extreme textural differences from the dredged material. Thus, if the dredged material was fine-textured, a coarse-textured marginal soil was chosen. All but two of the marginal soils (Mississippi and Minnesota) were sandy in nature. Three productive soils of medium texture were included in the study for comparison with the dredged material and marginal soils.

#### Structural relations

As compared with productive agricultural soils, the bulk densities, $D_B$, of the medium- to fine-textured dredged material samples were low, ranging from 0.67 to 1.24 $g/cm^3$. Bulk densities of two very coarse-textured

Table 9

Physical Characteristics of Dredged Material, Marginal Soils and their Mixtures

| Treatments | | Texture* | % 0.02-2.0mm Sand | % 0.002-0.02mm Silt | % 0.002mm Clay | Bulk Density $g/cm^3$ | Water Content by volume at: ($cm^3/cm^3$) 0.33 Bar | 15 Bar | Available Water Capacity ($cm^3/cm^3$) 0.33.-15 Bar | Saturated Hydraulic Conductivity (cm/hr) | COLE (cm/cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ala. | DM | C | 11.7 | 37.0 | 51.5 | 1.16 | 0.52 | 0.37 | 0.15 | 0.3 | 0.027 |
| | 2/3 DM | CL | 41.6 | 21.9 | 36.7 | 1.36 | 0.42 | 0.30 | 0.12 | 0.2 | 0.041 |
| | 1/3 DM | SCL | 63.5 | 15.7 | 21.0 | 1.51 | 0.29 | 0.17 | 0.12 | 1.1 | 0.031 |
| | Soil | LS | 83.0 | 14.6 | 2.5 | 1.73 | 0.15 | 0.07 | 0.08 | 5.3 | |
| Conn. | DM | SIL | 10.2 | 68.5 | 21.5 | 0.79 | 0.50 | 0.32 | 0.18 | 0.9 | 0.009 |
| | 2/3 DM | L | 38.0 | 43.6 | 18.6 | 1.03 | 0.44 | 0.15 | 0.29 | 0.8 | 0.004 |
| | 1/3 DM | SL | 65.9 | 22.4 | 11.8 | 1.36 | 0.31 | 0.10 | 0.21 | 0.9 | 0.002 |
| | Soil | S | 88.8 | 9.0 | 2.4 | 1.65 | 0.12 | 0.06 | 0.06 | 6.0 | |
| Ill. | DM | SIL | 21.7 | 63.0 | 15.4 | 0.74 | 0.43 | 0.22 | 0.21 | 5.4 | 0.019 |
| | 2/3 DM | L | 46.3 | 43.6 | 10.3 | 0.95 | 0.41 | 0.18 | 0.23 | 1.3 | 0.015 |
| | 1/3 DM | SL | 64.6 | 27.8 | 7.5 | 1.27 | 0.30 | 0.15 | 0.15 | 1.4 | 0.010 |
| | Soil | LS | 84.8 | 10.6 | 4.8 | 1.63 | 0.10 | 0.07 | 0.03 | 22.3 | |
| Mich. | DM | SL | 54.3 | 32.6 | 13.2 | 1.02 | 0.37 | 0.16 | 0.21 | 1.3 | 0.020 |
| | 2/3 DM | SL | 64.7 | 29.0 | 6.5 | 1.25 | 0.30 | 0.14 | 0.16 | 0.6 | 0.009 |
| | 1/3 DM | LS | 76.7 | 19.0 | 4.4 | 1.53 | 0.24 | 0.10 | 0.14 | 0.8 | 0.006 |
| | Soil | S | 88.4 | 8.3 | 3.5 | 1.71 | 0.10 | 0.05 | 0.05 | 10.4 | |
| Minn. | DM | S | 98.4 | 1.0 | 1.4 | 1.74 | 0.06 | 0.03 | 0.03 | 302.2 | |
| | 2/3 DM | SL | 70.3 | 17.3 | 12.6 | 1.62 | 0.23 | 0.17 | 0.06 | 3.7 | 0.040 |
| | 1/3 DM | L | 41.6 | 33.7 | 24.8 | 1.47 | 0.40 | 0.30 | 0.10 | 0.1 | 0.031 |
| | Soil | SIC | 10.8 | 47.9 | 41.5 | 1.29 | 0.49 | 0.36 | 0.13 | 0.1 | 0.058 |
| Miss. | DM | S | 96.7 | 1.3 | 2.1 | 1.67 | 0.07 | 0.04 | 0.03 | 94.7 | |
| | 2/3 DM | SL | 69.9 | 15.3 | 14.9 | 1.70 | 0.17 | 0.10 | 0.07 | 4.8 | 0.012 |
| | 1/3 DM | L | 44.1 | 40.6 | 15.5 | 1.64 | 0.29 | 0.18 | 0.11 | 0.2 | 0.019 |
| | Soil | SIL | 18.6 | 56.7 | 24.8 | 1.46 | 0.34 | 0.26 | 0.08 | 0.9 | 0.024 |
| N.J. | DM | SCL | 14.0 | 52.0 | 33.5 | 0.90 | 0.52 | 0.30 | 0.22 | 0.4 | 0.021 |
| | 2/3 DM | L | 39.9 | 40.0 | 20.3 | 1.09 | 0.36 | 0.19 | 0.17 | 1.8 | 0.054 |
| | 1/3 DM | SL | 67.3 | 22.7 | 10.1 | 1.34 | 0.26 | 0.14 | 0.12 | 2.8 | 0.004 |
| | Soil | S | 91.0 | 5.0 | 4.1 | 1.67 | 0.11 | 0.05 | 0.06 | 11.2 | |

Table 9 (concluded)

| Treatments | | Texture* | % 0.02-2.0mm Sand | % 0.002-0.02mm Silt | % 0.002mm Clay | Bulk Density $g/cm^3$ | Water Content by volume at: ($cm^3/cm^3$) 0.33 Bar | 15 Bar | Available Water Capacity (cm /cm ) 0.33-15 Bar | Saturated Hydraulic Conductivity (cm/hr) | COLE (cm/cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N.Y. | DM | SIL | 4.7 | 72.3 | 23.1 | 1.01 | 0.51 | 0.24 | 0.27 | 3.8 | 0.012 |
| | 2/3 DM | L | 29.5 | 49.2 | 21.4 | 1.11 | 0.39 | 0.12 | 0.27 | 1.1 | 0.013 |
| | 1/3 DM | SL | 55.8 | 28.7 | 15.6 | 1.26 | 0.34 | 0.15 | 0.19 | 0.4 | 0.016 |
| | Soil | LS | 80.9 | 10.7 | 8.6 | 1.34 | 0.23 | 0.14 | 0.09 | 7.4 | |
| Ohio | DM | SIC | 10.7 | 43.0 | 46.5 | 1.21 | 0.46 | 0.33 | 0.13 | 12.7 | 0.012 |
| | 2/3 DM | CL | 38.4 | 28.1 | 33.6 | 1.38 | 0.38 | 0.27 | 0.11 | 0.4 | 0.031 |
| | 1/3 DM | SL | 64.6 | 16.0 | 19.5 | 1.50 | 0.25 | 0.15 | 0.10 | 9.7 | 0.007 |
| | Soil | S | 91.8 | 4.3 | 4.0 | 1.60 | 0.12 | 0.08 | 0.04 | 22.3 | |
| S.C. | DM | C | 6.1 | 29.1 | 65.0 | 0.93 | 0.55 | 0.41 | 0.14 | 2.2 | 0.074 |
| | 2/3 DM | CL | 42.7 | 18.8 | 38.7 | 1.10 | 0.44 | 0.34 | 0.10 | 1.7 | 0.031 |
| | 1/3 DM | SCL | 70.0 | 9.7 | 23.2 | 1.29 | 0.28 | 0.24 | 0.04 | 9.6 | 0.011 |
| | Soil | S | 95.8 | 4.0 | 0.4 | 1.44 | 0.13 | 0.06 | 0.07 | 30.8 | |
| Nicol. | | L | 45.7 | 28.4 | 26.1 | 1.37 | 0.33 | 0.23 | 0.10 | 3.0 | 0.027 |
| Bold | | L | 33.1 | 46.8 | 20.3 | 1.39 | 0.29 | 0.18 | 0.11 | 0.6 | 0.003 |
| Wauk. | | SIL | 24.7 | 52.4 | 23.1 | 1.36 | 0.34 | 0.23 | 0.11 | 0.6 | 0.017 |

S = Sand, SI = Silt, C = Clay, L = Loam

dredged material samples (Minnesota, $D_B$ = 1.59 g/cm$^3$; and Mississippi, $D_B$ = 1.50 g/cm$^3$) were similar to agricultural soils of the same texture.

The differences in bulk density values for the dredged material samples were associated with clay and organic carbon contents. The low bulk density of Illinois dredged material was associated with high organic matter content, whereas the low bulk density of the South Carolina dredged material was related to both high clay and relatively high organic matter contents. The Minnesota dredged material had a high bulk density because of a large quantity of coarse sand and the small organic carbon content.

In all instances, addition of a fine-textured dredged material to a coarse-textured marginal soil resulted in a lower bulk density for the mixture. For example, the bulk densities from the Alabama treatments were 1.16 g/cm$^3$ for the pure dredged material, 1.36 g/cm$^3$ for the 2/3 dredged material, 1.51 g/cm$^3$ for the 1/3 dredged material, and 1.73 g/cm$^3$ for the pure marginal soil.

Soil water retention

Soil water retention values are related to the textural and structural characteristics of both dredged material and soil. The soil water retention values were usually greater in the eight fine-textured dredged material samples than in the productive Minnesota soils, particularly at low matrix suctions (Figure 5, Appendix A, Figures A1 to A8). When the fine-textured dredged material was mixed with sandy marginal soils the soil water retention curves were similar to those of the productive Minnesota soils, particularly the 1/3 dredged material treatment.

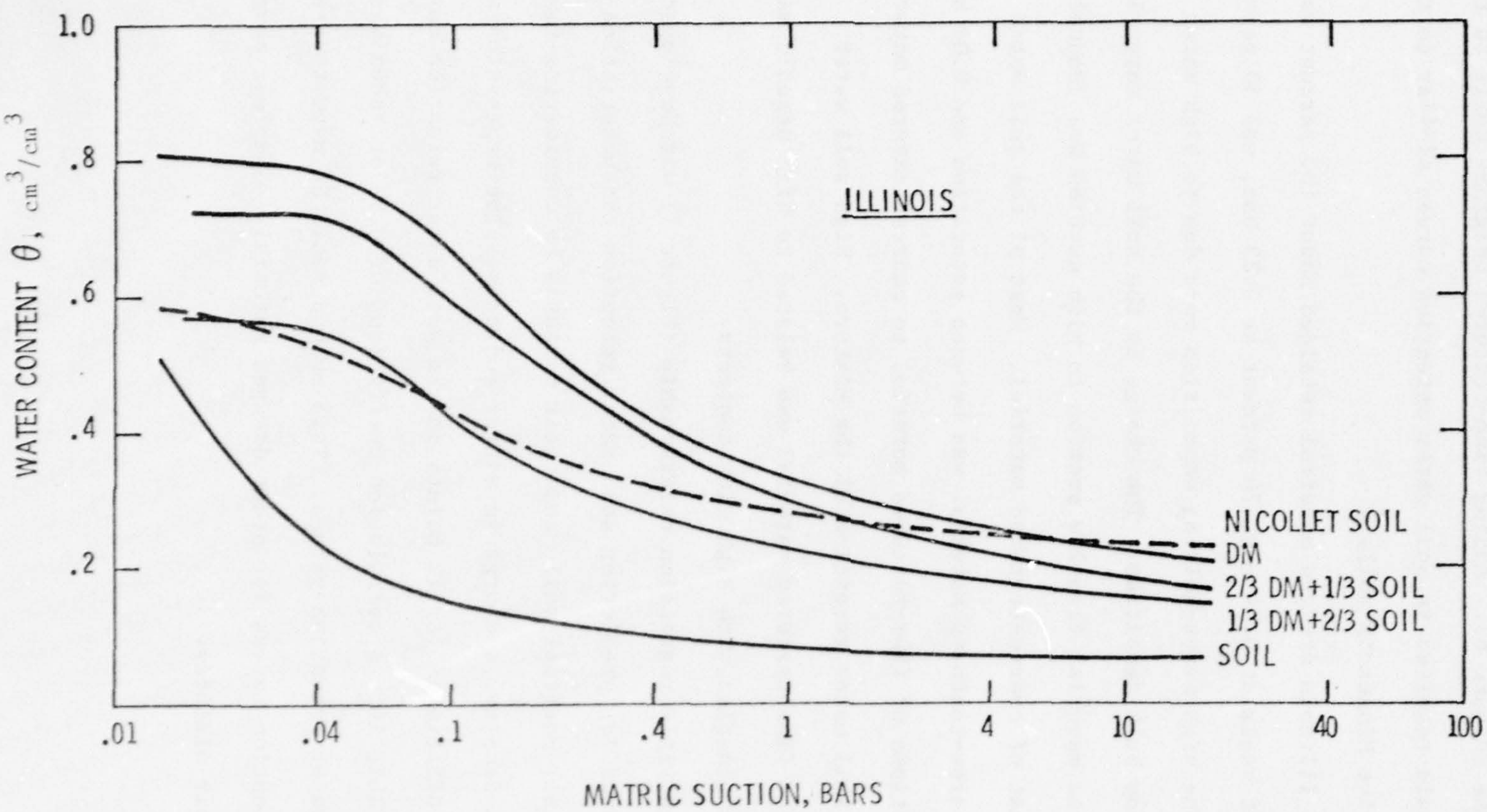


Figure 5. Soil water retention curve for Illinois treatments and for a Nicollet soil

days and continued at 1-week intervals at the rate of 55 kg/ha.



The two coarse-textured dredged material samples had low water retention values (Figure 6). Adding fine-textured marginal soils to these dredged materials resulted in soil water retention curves similar to those of the productive Minnesota soils.

The Illinois dredged material retained about 100 percent water on a dry weight basis at 0.04 bar, 70 percent at 0.33 bar, and 30 percent at 15 bars. The high water-holding capacities were due to high water contents and low bulk densities. The change in the soil water retention of fine-textured material from low suction to high suction was gradual compared to that of coarse-textured material. Most of the soil water retained by coarse-textured material was between saturation and 0.04 bar suction. Additions of fine-textured material to coarse-textured material increased the soil water retention of the mixture. High soil water retention in the fine-textured material was related to high organic matter contents in combination with high clay contents.

A multiple regression relationship (Figure 7) was developed which can be used for predicting soil water retention characteristics of dredged material, marginal soil, and their mixtures by considering textural analyses, bulk density, and organic matter contents. The regression and correlation coefficients for 12 points on the soil water retention curves are given in Table 10. A correlation coefficient of 0.95 or above was found for all soil water retention values. This method could be used to preduct soil water retention curves for other dredged material samples, marginal soils, and their mixtures.

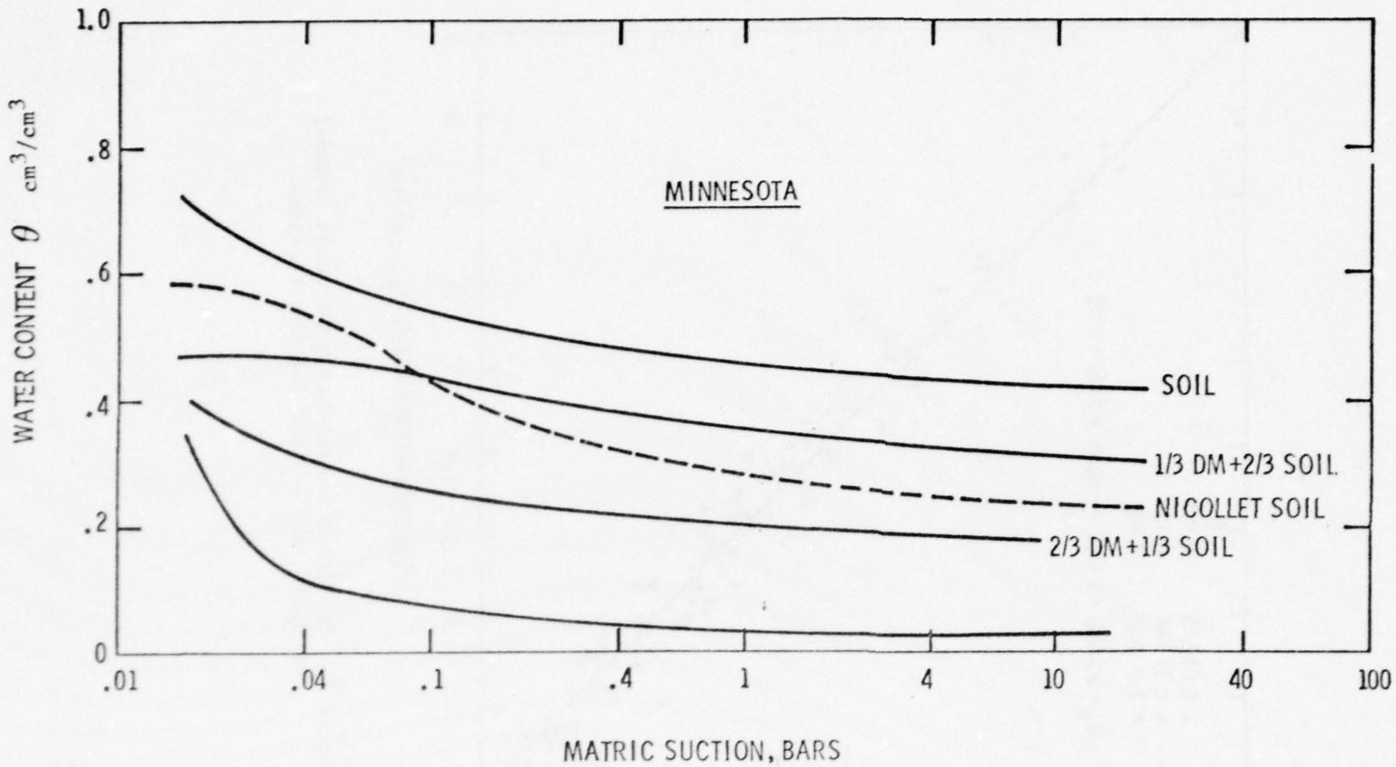


Figure 6. Soil water retention curve for Minnesota treatments and for a Nicollet soil

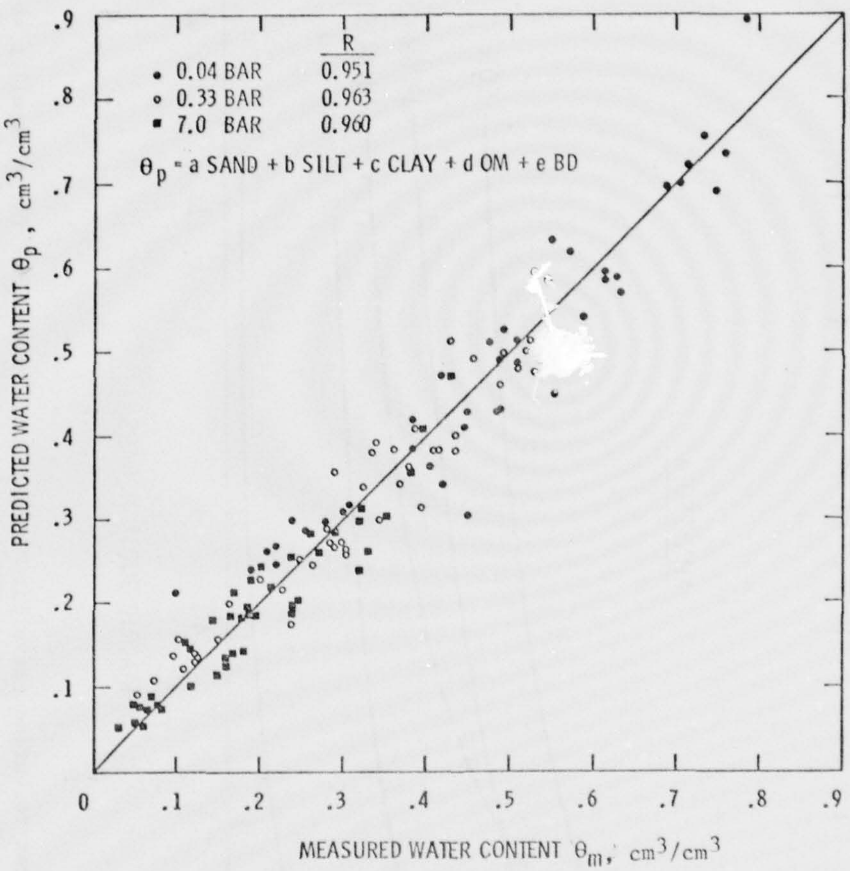


Figure 7. Predicted versus measured water content at 0.04-, 0.33-, and 7.0-bar suctions

Table 10

Correlation and Regression Coefficients for Prediction of Moisture Retention Curves

| Suction (bars) | Regression Coefficients $a \times 10^3$ | $b \times 10^3$ | $c \times 10^3$ | $d \times 10^3$ | $e \times 10^2$ | Correlation Coefficient (R) |
|---|---|---|---|---|---|---|
| .04 | 6.995 | 9.688 | 10.29 | 8.332 | -32.47 | 0.951 |
| .07 | 5.599 | 8.981 | 9.150 | 7.673 | -26.56 | 0.958 |
| .10 | 5.176 | 8.519 | 9.078 | 4.852 | -25.25 | 0.960 |
| .20 | 3.970 | 6.991 | 8.531 | 2.516 | -19.13 | 0.962 |
| .33 | 3.133 | 5.858 | 8.024 | 2.264 | -14.59 | 0.963 |
| .60 | 2.263 | 4.591 | 7.476 | 2.461 | - 9.773 | 0.965 |
| 1.0 | 1.638 | 3.669 | 7.057 | 2.685 | - 6.270 | 0.967 |
| 2.0 | 0.967 | 2.643 | 6.610 | 2.646 | - 2.502 | 0.970 |
| 4.0 | 0.557 | 1.976 | 6.325 | 2.315 | - 0.393 | 0.966 |
| 7.0 | 0.318 | 1.580 | 6.103 | 2.238 | 0.787 | 0.960 |
| 10.0 | 0.260 | 1.455 | 6.026 | 1.879 | 0.987 | 0.955 |
| 15.0 | 0.222 | 1.339 | 5.909 | 1.801 | 1.065 | 0.951 |

$\theta p$ = a sand (%) + b silt (%) + c clay (%) + d organic matter (%) + e bulk density (g/cm$^3$).

$\theta p$ = Predicted water content for a given suction.



probe. These bulk densities were close to the air-dry bulk densities

In some samples, the hydraulic conductivity continuously decreased with



Available water capacity

The percent water a soil will retain and have available for plant growth is estimated in the laboratory as the difference between the 0.33- and 15-bar soil water retention values. These values for the mixtures (Table 9) are intermediate between the values for the dredged material and marginal soil alone and are linearly related. The water contents at the 0.33-bar values were higher for all treatments for the productive Minnesota soils with the exception of the dredged material samples. Therefore, applications of fine-textured dredged material to coarse-textured marginal soils will improve the available water capacity of the mixture.

Hydraulic conductivity

Saturated hydraulic conductivity measurements made in the laboratory on the ground and packed dredged material and marginal soils are given in Table 9. Saturated hydraulic conductivity of coarse-textured materials was considerably higher than that of fine-textured materials. For the eight fine-textured dredged material samples the hydraulic conductivity was lower for a given water content than for the three Minnesota productive soils. The hydraulic conductivity values of these treatments were usually high when compared with field values (2 to 5 cm/hr) found in the literature. Unsaturated hydraulic conductivities as shown in Figure 8 show that for the dredged material-marginal soil mixtures the conductivities are intermediate between those for the two materials alone (Appendix A, Figure A10). However, the hydraulic conductivities at 0.1 and 0.33 bar did not differ greatly within treatments. For example, at the 0.33-bar soil water retention value the unsaturated hydraulic conductivities for

Table 8.



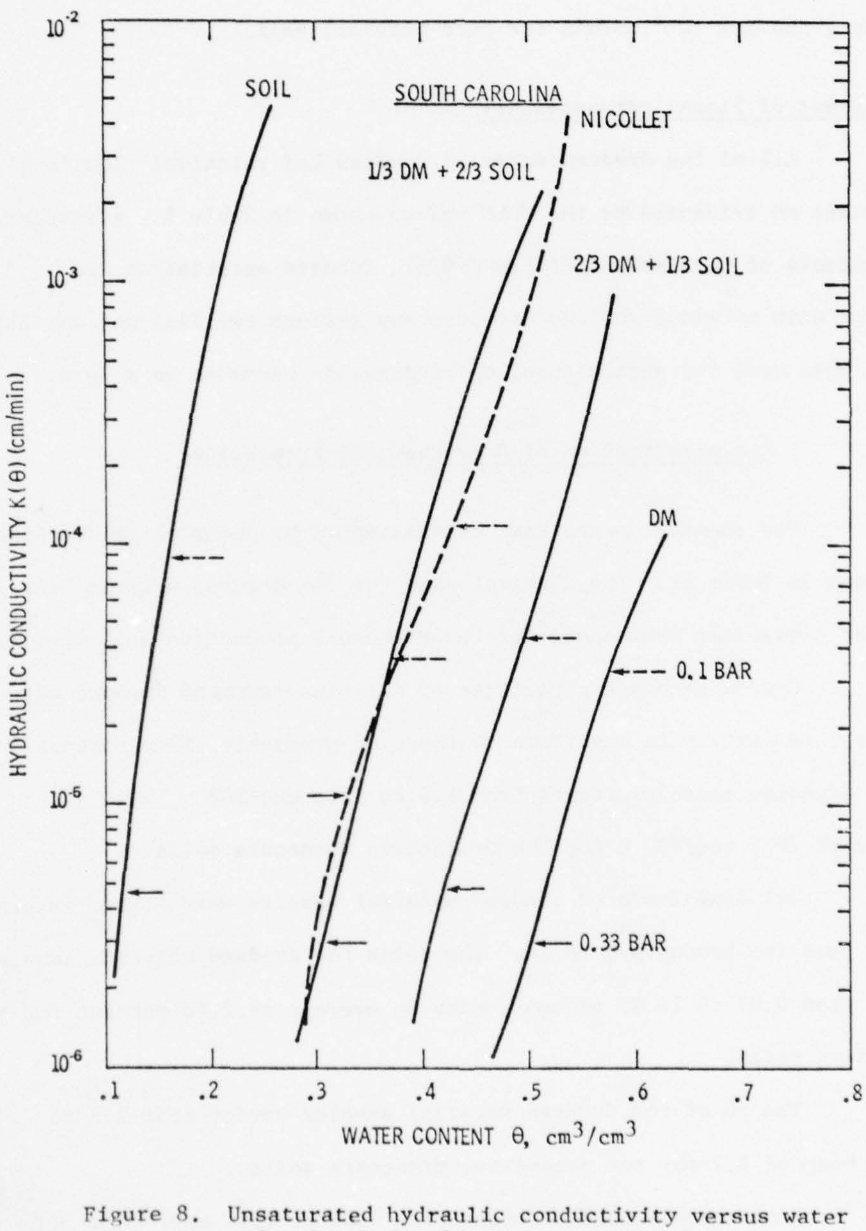


Figure 8. Unsaturated hydraulic conductivity versus water content for South Carolina treatments and for a Nicollet soil

South Carolina treatments were $3 \times 10^{-6}$ cm/min for pure dredged material, $3 \times 10^{-6}$ cm/min for 2/3 dredged material, $5 \times 10^{-6}$ cm/min for 1/3 dredged material, and $5 \times 10^{-6}$ cm/min for pure marginal soil.

Coefficient of linear extensibility

All of the dredged material samples had relatively low swelling properties as evidenced by the COLE values shown in Table 9. According to the criteria of Schafer and Singer (1976), dredged material or its mixtures with marginal soil do not pose any serious swelling and shrinking hazard when used for agricultural or engineering purposes on a farm.

## Characterization of Soil Chemical Properties

The chemical properties of treatments by geographical location are shown in Table 11. The chemical data for the dredged material samples were not dissimilar from those for the Minnesota productive soil samples.

Cation exchange capacities of all fine-textured dredged material samples were similar in magnitude to those of productive Minnesota soils. Cation exchange capacity ranged from 1.0 to 32.5 meq/100 g, with an average of 20.7 meq/100 g for the productive Minnesota soils.

All fine-textured dredged material samples were higher in organic matter than the productive soils. The range for dredged material samples varied from 0.07 to 13.05 percent, with an average of 2.43 percent for the productive soils.

The pH of the dredged material samples varied from 2.9 to 7.9, with a mean of 6.2 for the productive Minnesota soils.

Exchangeable sodium ranged from 0.01 to 1.14 meq/100 g and exchangeable potassium varied from 0.01 to 1.52 meq/100 g. The range in

Table 11

Chemical Properties of Soils and Dredged Material

| Soil or Dredged Material (D.M.) | | % OM | CEC (meq/100 g) | Exchangeable Cations Na | K | Ca | Mg | EC (mmhos/cm) | Total % N | ($NO_3$-N) | Total P µg/g | Total S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | ———(meq/100 g)——— | | | | | | | | |
| Ala. | D.M. | 10.76 | 32.5 | 1.14 | 1.52 | 15.62 | 9.29 | 5.63 | 0.30 | 4.87 | 1270 | 9710 |
| | Soil | 1.93 | 3.9 | 0.02 | 0.04 | 0.15 | 0.04 | 0.04 | 0.04 | 2.19 | 677 | 282 |
| Conn. | D.M. | 5.93 | 14.4 | 0.16 | 0.31 | 0.63 | 0.08 | 0.74 | 0.20 | 2.07 | 1120 | 8320 |
| | Soil | 1.79 | 3.6 | 0.01 | 0.11 | 0.61 | 0.04 | 0.38 | 0.07 | 4.39 | 687 | 313 |
| Ill. | D.M. | 22.45 | 19.2 | 0.02 | 0.01 | -- | -- | 1.14 | 0.64 | 16.01 | 490 | 7075 |
| | Soil | 0.09 | 4.2 | N.D. | 0.15 | 2.92 | 0.99 | 0.04 | 0.05 | 8.38 | 224 | 515 |
| Mich. | D.M. | 9.82 | 12.3 | 0.01 | 0.01 | -- | -- | 1.64 | 0.26 | 166.18 | 1200 | 2720 |
| | Soil | 1.02 | 2.8 | N.D. | 0.27 | 1.48 | 0.56 | 0.57 | 0.04 | 9.83 | 540 | 355 |
| Minn. | D.M. | 0.72 | 1.0 | 0.03 | 0.04 | --** | -- | 0.18 | 0.01 | 10.89 | 241 | 870 |
| | Soil | 6.12 | 31.1 | N.D. | 0.44 | -- | -- | 0.13 | 0.26 | 16.15 | 1210 | 1370 |
| Miss. | D.M. | 0.12 | 1.6 | 0.19 | 0.11 | -- | -- | 0.02 | 0.01 | 1.95 | 112 | 475 |
| | Soil | 1.72 | 19.1 | N.D. | 0.18 | -- | -- | 0.16 | 0.10 | 29.10 | 793 | 1245 |
| N.J. | D.M. | 7.09 | 22.3 | 0.32 | 0.95 | 11.70 | 3.00 | 0.60 | 0.28 | 44.97 | 2580 | 2760 |
| | Soil | 1.50 | 2.6 | 0.01 | 0.05 | 0.09 | 0.03 | 0.45 | 0.05 | 4.07 | 352 | 475 |
| N.Y. | D.M. | 8.55 | 8.3 | 0.01 | 0.27 | -- | -- | 1.31 | 0.25 | 9.43 | 1350 | 5840 |
| | Soil | 4.97 | 9.1 | N.D. | 0.15 | 2.00 | 0.27 | 0.05 | 1.80 | 7.07 | 352 | 690 |
| Ohio | D.M. | 6.67 | 21.94 | 0.03 | 0.05 | -- | -- | 0.55 | 0.22 | 10.45 | 1430 | 2620 |
| | Soil | 1.53 | 5.0 | N.D. | 0.11 | 0.63 | 0.12 | 0.44 | 0.06 | 5.56 | 224 | 583 |
| S.C. | D.M. | 8.65 | 31.0 | 0.96 | 1.35 | 10.21 | 12.03 | 4.49 | 0.35 | 19.02 | 1370 | 4430 |
| | Soil | 1.72 | 2.2 | 2.02 | 0.02 | 0.67 | 0.42 | 0.38 | 0.03 | 1.70 | 645 | 272 |

** Not reported as pH >7.0.

Table 11 (concluded)

| Soil or Dredged Material (D.M.) | | % OM | CEC (meq/100 g) | Exchangeable Cations Na | K | Ca | Mg | EC (mmhos/cm) | Total % N | ($NO_3$-N) | Total P | Total S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (meq/100 g) | | | | | | | μg/g | |
| Wauk. | Soil | 4.06 | 21.2 | N.D. | 0.04 | 13.85 | 0.99 | 0.12 | 0.19 | 11.55 | 694 | 1065 |
| Port B. | Soil | 4.13 | 16.3 | N.D. | 0.03 | 4.51 | 0.78 | 0.93 | 0.19 | 9.87 | 689 | 1055 |
| Nicol. | Soil | 4.37 | 24.6 | 0.01 | 0.01 | 7.39 | 0.91 | 1.43 | 0.23 | 21.49 | 568 | 1210 |

exchangeable calcium was 0.63 to 15.6 meq/100 g. Concentrations of exchangeable cations in the dredged material were within the normal ranges found in agricultural soils. Exchangeable sodium was low except in the Alabama and South Carolina dredged material. In these samples, the exchangeable sodium percentage was about 3, which should not create plant growth problems but could cause soil structural problems.

Because of dissolution of calcium carbonate during ammonium acetate leaching, measured concentrations of exchangeable calcium and magnesium are not reliable for soils containing calcium carbonate. Thus, exchangeable calcium and magnesium are not reported for dredged material or marginal soils with pH above 7.0.

The electrical conductivity of the dredged material was less than 2.0 mmho/cm with the exception of the dredged material from South Carolina and Alabama. All of the dredged material samples were acceptable for agricultural crop production when compared to the electrical conductivity recommendations presented in Table 1. However, germination and growth of salt-sensitive crops may be adversely affected on the South Carolina and Alabama dredged material because their electrical conductivities are greater than 2.0 mmho/cm.

## Soil Chemical Tests for Plant Nutrients

Soil test results for the dredged material, marginal soil, and productive soil analyzed prior to the greenhouse experiment are summarized in Table 12. Values for pH of dredged material ranged from 3.1 to 7.6 with four of the dredged material samples needing the addition of lime for optimal plant growth. Lack of lime would severely restrict growth of

Table 12

Results of Initial Soil Test on Soils and Dredged Material

| Soil or Dredged Material (D.M.) | | pH ($H_2O$) | Buffer Index | Lime Req. (metric tons/ha) | P (kg/ha) | K (kg/ha) | S µg/g |
|---|---|---|---|---|---|---|---|
| Ala. | D.M. | 4.7 | 5.7 | 19.5 | 120 | 1277 | 1300 |
| | 2/3 D.M. | 4.7 | 5.7 | 19.0 | 81 | 672+ | 980 |
| | 1/3 D.M. | 4.6 | 5.9 | 16.8 | 75 | 504 | 600 |
| | Soil | 4.6 | 6.2 | 13.4 | 7 | 34 | 12 |
| Conn. | D.M. | 2.9 | 5.1 | 20.2 | 68 | 112 | 530 |
| | 2/3 D.M. | 3.3 | 5.3 | 20.2 | 75 | 123 | 260 |
| | 1/3 D.M. | 3.7 | 5.6 | 20.2 | 101 | 101 | 150 |
| | Soil | 5.1 | 6.3 | 12.3 | 194 | 90 | 11 |
| Ill. | D.M. | 7.6 | -- | -- | 4 | 95 | 220 |
| | 2/3 D.M. | 7.5 | -- | -- | 6* | 101 | 100 |
| | 1/3 D.M. | 7.5 | -- | -- | 6* | 95 | 50 |
| | Soil | 6.9 | -- | -- | 24 | 90 | 10 |
| Mich. | D.M. | 7.4 | -- | -- | 11 | 162 | 180 |
| | 2/3 D.M. | 7.1 | -- | -- | 18 | 212 | 120 |
| | 1/3 D.M. | 7.1 | -- | -- | 113 | 213 | 60 |
| | Soil | 6.2 | -- | -- | 178 | 213 | 9 |
| Minn. | D.M. | 7.9 | -- | -- | 39 | 28 | 26 |
| | 2/3 D.M. | 7.3 | -- | -- | 77 | 151 | 27 |
| | 1/3 D.M. | 7.4 | -- | -- | 103 | 241 | 24 |
| | Soil | 7.4 | -- | -- | 122 | 358 | 20 |
| Miss. | D.M. | 7.4 | -- | -- | 40 | 34 | 10 |
| | 2/3 D.M. | 6.3 | -- | -- | 58 | 146 | 14 |
| | 1/3 D.M. | 5.8 | 6.7 | 6.7 | 88 | 230 | 12 |
| | Soil | 5.7 | 6.6 | 9.0 | 97 | 325 | 13 |
| N.J. | D.M. | 4.6 | 5.9 | 16.8 | 85 | 661 | 280 |
| | 2/3 D.M. | 4.8 | 5.9 | 16.8 | 123 | 437 | 160 |
| | 1/3 D.M. | 4.6 | 6.1 | 14.6 | 113 | 246 | 50 |
| | Soil | 4.3 | 6.3 | 12.3 | 139 | 50 | 26 |
| N.Y. | D.M. | 7.4 | -- | -- | 58 | 95 | 460 |
| | 2/3 D.M. | 7.0 | -- | -- | 58 | 123 | 580 |
| | 1/3 D.M. | 6.6 | -- | -- | 66 | 123 | 240 |
| | Soil | 5.0 | 5.8 | 17.9 | 64 | 106 | 34 |

* P test ran with 1 g soil to 50 ml extracting solution. All other values based on a 1:10 extraction.

Table 12 (concluded)

| Soil or Dredged Material (D.M.) | | pH ($H_2O$) | Buffer Index | Lime Req. (metric tons/ha) | P (kg/ha) | K (kg/ha) | S μg/g |
|---|---|---|---|---|---|---|---|
| Ohio | D.M. | 7.6 | -- | -- | 64 | 353 | 120 |
| | 2/3 D.M. | 7.4 | -- | -- | 94 | 258 | 80 |
| | 1/3 D.M. | 7.1 | -- | -- | 110 | 168 | 40 |
| | Soil | 4.9 | 6.0 | 15.7 | 85 | 56 | 14 |
| S.C. | D.M. | 4.6 | 5.6 | 20.2 | 18 | 1098 | 1050 |
| | 2/3 D.M. | 4.6 | 5.8 | 17.9 | 30 | 672+ | 740 |
| | 1/3 D.M. | 4.6 | 6.1 | 14.6 | 40 | 482 | 360 |
| | Soil | 5.0 | 6.8 | 6.7 | 7 | 34 | 8 |
| Wauk. Soil | | 7.1 | -- | -- | 88 | 302 | 13 |
| Port B. Soil | | 5.6 | 6.1 | 14.6 | 92 | 330 | 13 |
| Nicol. Soil | | 6.0 | 6.5 | 10.1 | 36 | 179 | 16 |

most agricultural crops on the Alabama, Connecticut, New Jersey, and South Carolina dredged material. Additions of lime would be needed on seven of the marginal soils to raise their pH to the expected value of 6.5. The increase in pH of the dredged material from Alabama, Connecticut, New Jersey, and South Carolina by the addition of lime was less than that predicted by the Minnesota Soil Testing Service (compare Table 12 and Table 13). For example, in the Alabama dredged material, the initial pH was 4.7 (Table 12). Then lime was added at a rate of 19.0 metric tons/ha, which was expected to raise the pH to 6.5. However, after the greenhouse experiment was completed 3 months later, the pH had increased to only 5.0 (Table 13). Similar results were obtained with the South Carolina dredged material where the pH was raised from 4.6 to 5.6. The initial pH was 3.1 for the Connecticut dredged material; however, three times the normal rate of application of lime (normal = 20 metric tons/ha) was required to increase the pH to 6.4. These three dredged materials contained large amounts of total sulfur (Table 12). The sulfur in the original dredged material was in a reduced inorganic form which oxidized to sulfate upon air drying and under the aerated soil conditions of the greenhouse experiment. In this study, large amounts of lime ($CaCO_3$) were applied to neutralize the acidity produced upon oxidation of sulfur.

The concentration of available phosphorus was high in seven of the dredged material samples, was medium in one sample, and was low in two of the dredged material samples. When a dredged material with a high concentration of available phosphorus was mixed with a marginal soil with a low concentration of available phosphorus, the phosphorus level of the mixture was somewhere between the two (Table 12). The concentration

Table 13

Results of Soil Test on Soils and Dredged Material after Barley Growth Experiments. Averages and their Standard Errors, s.e., are Given

| Soil, Dredged Material, or Mixture | | pH $H_2O$ | pH s.e. | Phosphorus kg/ha | Phosphorus s.e. | Potassium kg/ha | Potassium s.e. |
|---|---|---|---|---|---|---|---|
| Ala. | D.M. | 5.0* | 0.02 | 68 | 4.7 | 1577 | 18.5 |
| | 2/3 D.M. | 5.1* | 0.02 | 85 | 5.2 | 1192 | 61.6 |
| | 1/3 D.M. | 5.5* | 0.02 | 100 | 1.6 | 804 | 30.1 |
| | Soil | 6.7 | 0.08 | 39 | 2.4 | 260 | 19.7 |
| Conn. | D.M. | 6.4 | 0.02 | 49 | 2.1 | 250 | 25.0 |
| | 2/3 D.M. | 6.5 | 0.02 | 93 | 0.6 | 255 | 25.5 |
| | 1/3 D.M. | 6.6 | 0.04 | 190 | 1.1 | 251 | 25.2 |
| | Soil | 6.5 | 0.04 | 374 | 11.7 | 254 | 19.9 |
| Ill. | D.M. | 7.4 | 0.03 | 19** | 1.4 | 121 | 13.1 |
| | 2/3 D.M. | 7.4 | 0.02 | 18** | 1.3 | 141 | 17.6 |
| | 1/3 D.M. | 7.5 | 0.02 | 10** | 0.7 | 176 | 14.1 |
| | Soil | 6.3 | 0.05 | 41 | 1.1 | 430 | 18.4 |
| Mich. | D.M. | 7.3 | 0.02 | 16 | 0.2 | 169 | 4.8 |
| | 2/3 D.M. | 7.3 | 0.0 | 27 | 1.4 | 179 | 4.3 |
| | 1/3 D.M. | 7.4 | 0.02 | 181 | 2.5 | 212 | 18.9 |
| | Soil | 5.8 | 0.10 | 361 | 55.8 | 541 | 97.6 |
| Minn. | D.M. | 7.4 | 0.0 | 49 | 1.9 | 214 | 19.3 |
| | 2/3 D.M. | 7.4 | 0.02 | 76 | 2.8 | 243 | 6.0 |
| | 1/3 D.M. | 7.4 | 0.02 | 127 | 5.7 | 305 | 12.5 |
| | Soil | 7.4 | 0.04 | 133 | 4.0 | 370 | 15.0 |
| Miss. | D.M. | 6.5 | 0.03 | 87 | 2.5 | 209 | 18.3 |
| | 2/3 D.M. | 6.0 | 0.09 | 77 | 2.6 | 392 | 38.4 |
| | 1/3 D.M. | 6.4 | 0.20 | 94 | 3.4 | 402 | 3.7 |
| | Soil | 6.8 | 0.02 | 109 | 2.3 | 432 | 10.2 |
| N.J. | D.M. | 6.0 | 0.04 | 88 | 5.8 | 461 | 23.1 |
| | 2/3 D.M. | 5.9 | 0.33 | 137 | 3.9 | 353 | 12.0 |
| | 1/3 D.M. | 6.2 | 0.06 | 244 | 12.9 | 317 | 36.4 |
| | Soil | 6.4 | 0.04 | 161 | 5.8 | 239 | 41.2 |

* Buffer pH values also determined.

** P test ran with 1 g soil to 50 ml extracting solution. All other values based on a 1:10 extraction.

Table 13 (concluded)

| Soil, Dredged Material, or Mixture | | pH $H_2O$ | s.e. | Phosphorus kg/ha | s.e. | Potassium kg/ha | s.e. |
|---|---|---|---|---|---|---|---|
| N.Y. | D.M. | 7.3 | 0.02 | 24 | 2.1 | 288 | 7.6 |
| | 2/3 D.M. | 7.2 | 0.02 | 29 | 1.1 | 333 | 69.2 |
| | 1/3 D.M. | 7.0 | 0.02 | 57 | 2.5 | 226 | 24.9 |
| | Soil | 6.2 | 0.05 | 75 | 1.9 | 463 | 25.4 |
| Ohio | D.M. | 7.6 | 0.02 | 103 | 1.7 | 361 | 13.2 |
| | 2/3 D.M. | 7.6 | 0.02 | 133 | 1.0 | 242 | 8.6 |
| | 1/3 D.M. | 7.5 | 0.02 | 162 | 2.1 | 226 | 2.4 |
| | Soil | 6.7 | 0.03 | 97 | 2.4 | 316 | 23.3 |
| S.C. | D.M. | 5.6* | 0.02 | 25 | 1.8 | 1261 | 21.8 |
| | 2/3 D.M. | 5.7* | 0.00 | 34 | 1.4 | 997 | 19.4 |
| | 1/3 D.M. | 6.1 | 0.02 | 46 | 1.0 | 666 | 57.1 |
| | Soil | 6.4 | 0.04 | 48 | 4.5 | 341 | 25.9 |
| Wauk. Soil | | 6.6 | 0.03 | 76 | 1.7 | 355 | 12.9 |
| Bold Soil | | 6.6 | 0.02 | 73 | 1.0 | 382 | 11.9 |
| Nicol. Soil | | 6.7 | 0.02 | 40 | 0.4 | 343 | 7.7 |

of potassium was high in four of the dredged material samples, was medium in one sample, and was low in five dredged material samples. Only a minimal amount of phosphorus or potassium fertilizer would be needed for most crops when the soil tests were high. The level of available sulfur was high on all dredged material samples except one, which tested medium. Thus, sulfur fertilizer would not be needed.

## Clay Mineralogy

X-ray diffraction patterns of dredged material samples are given in Figures 9 and 10 and Appendix B, Figures B1 through B8. The X-ray diffractogram for the Ohio dredged material showed some expanding material in the 14- to 17-Å range and a 14-Å chlorite or vermiculite peak, but was primarily composed of 10-Å mica as shown in Figure 9. When the sample was potassium-saturated and heated to 100°C for 24 hours, the expanded material partially collapsed with some intensification of a 10-Å mica peak confirming the presence of 2:1 expanding clay minerals.

The South Carolina X-ray diffractogram evidenced some expanding material in the 14- to 17-Å range and a slight 14-Å chlorite or vermiculite peak, but was primarily composed of a 7- to 13-Å kaolinite peak as shown in Figure 10. When the South Carolina dredged material was potassium-saturated and heated to 110°C, a partial collapse of the expanding material occurred, confirming the presence of 2:1 expanding clay minerals.

The apparent amorphous nature of the clay fraction of many of the dredged material (Appendix B, Figures B2 through B8) samples partially explains the high soil water retention values.

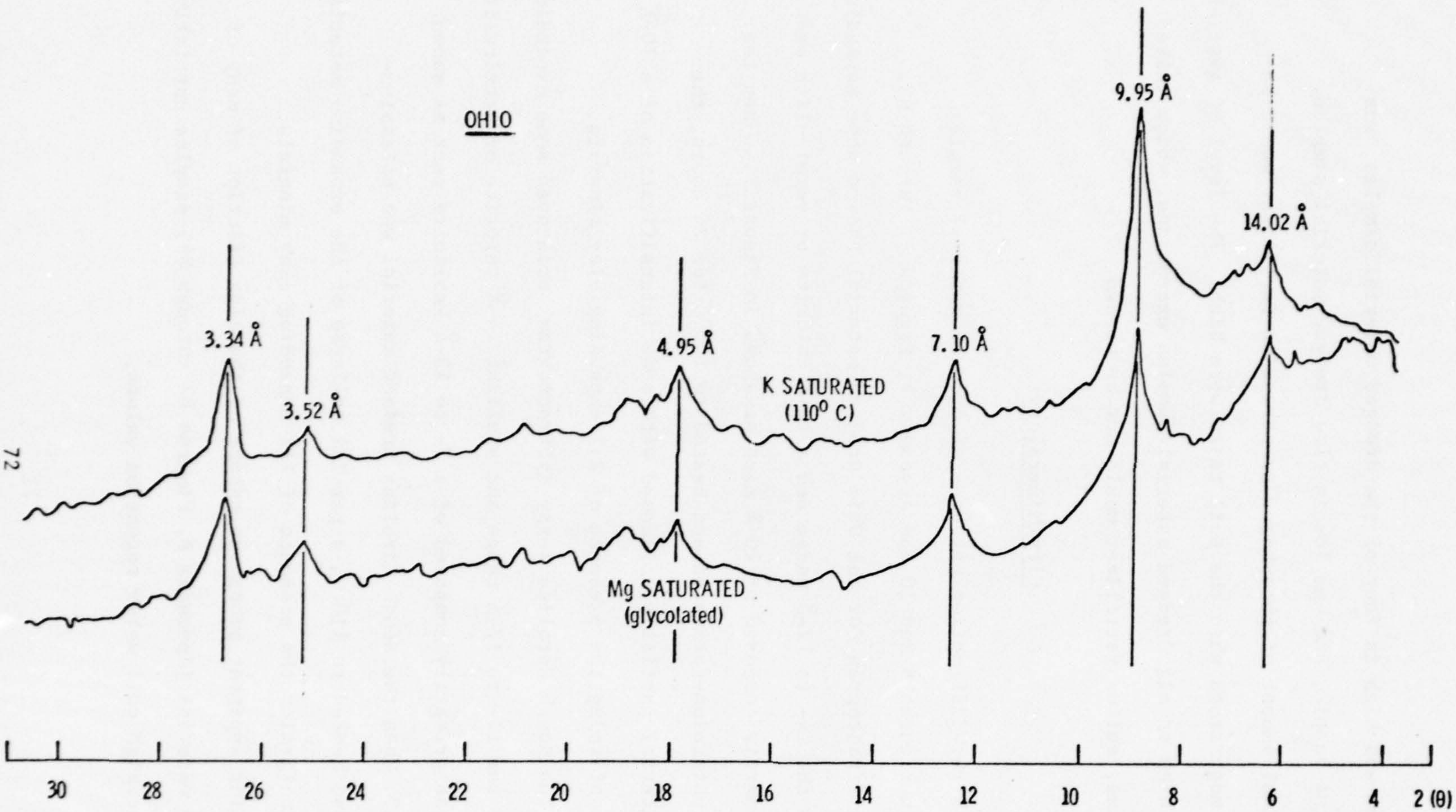


Figure 9. X-ray diffractogram of Ohio dredged material

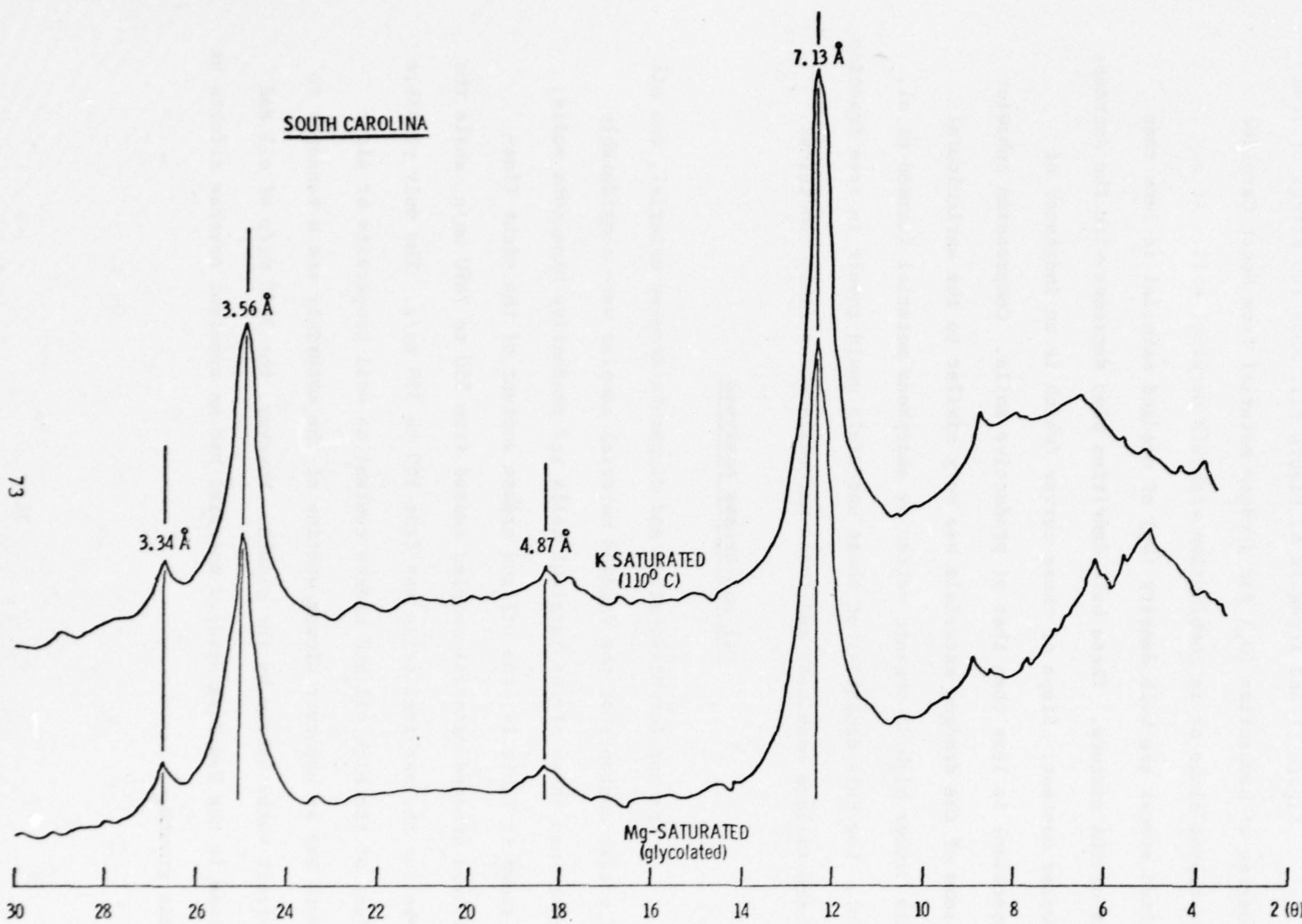


Figure 10. X-ray diffractogram of South Carolina dredged material

Figure 11 and Appendix A, Figure A11, show the effect of load on degree of compaction ($D_B$) for dredged material from South Carolina when tested alone or in combination with 2/3 marginal soil. At any applied stress the bulk density ($D_B$) of dredged material is less than that of the mixture. These bulk densities also decrease with the decrease in water content. Slope of these curves (which is an indicator of compaction) is less than that of productive soils. Compression behavior of some of the dredged materials was very similar to the agricultural soils either high in organic matter or amorphous material (Larson et al. 1978). Low bulk densities of these materials would result in less traction between tillage machinery and these materials under field conditions.

## Oil and Grease Analyses

Except for Mississippi and Minnesota dredged material, the oil and grease contents of the dredged material samples were considerably higher than those of the marginal soils and productive Minnesota soils. As shown in Table 14, the oil and grease content of the eight fine-textured dredged material samples ranged from 550 to 7890 mg/g, while the range for the marginal soils was from 140 to 350 mg/g. The only possible effect of the high oil and grease content on soil properties or plant growth was an apparent slower wetting of the materials and a tendency to restrict water uptake by the plants. However, the 7890 mg/g of oil and grease in the New York dredged material had no apparent adverse effects on plant growth.

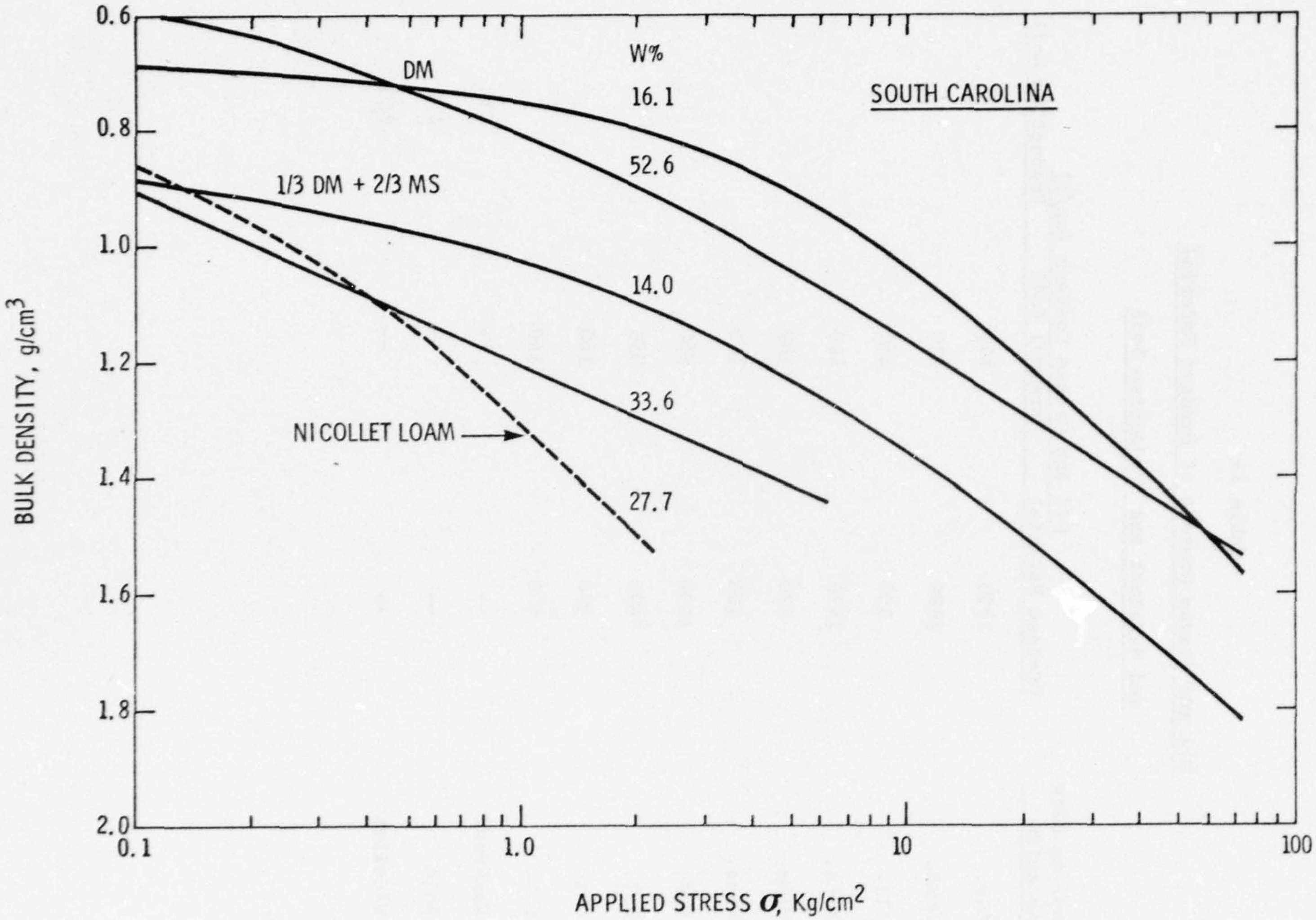


Figure 11. Effect of applied stress on bulk density of dredged material and its mixture from South Carolina

Table 14

Oil and Grease Content of Dredged Material

and Marginal and Productive Soil

| Sampling Site Location | Oil and Grease Content (μg/l) Dredged Material | Marginal Soil | Productive Soil |
|---|---|---|---|
| Ala. | 2750 | 140 | |
| Conn. | 2090 | 210 | |
| Ill. | 550 | 150 | |
| Mich. | 1470 | 140 | |
| Minn. | 170 | 180 | |
| Miss. | 180 | 170 | |
| N.J. | 1430 | 260 | |
| N.Y. | 7890 | 350 | |
| Ohio | 970 | 160 | |
| S.C. | 800 | 160 | |
| Waukegan | -- | -- | 230 |
| Bold | -- | -- | 230 |
| Nicollet | -- | -- | 210 |

## Plant Growth

Photographs of plant growth were taken before each harvest. The photographs presented and discussed below show plant growth differences among various treatments for both second crop of barley and second cutting of annual ryegrass. Photographs of first crop of barley and first and third cutting of rye (not included) also showed similar differences in plant growth.

Comparisons of plant growth on the three productive Minnesota control soils are shown in Figures 12 and 13. The photographs show that the yield was equivalent for each pot; however, the total yield on the Nicollet soil was less than the other two at the end of the study (Tables 15 and 16).

The notation below each pot in Figures 14 through 34 identifies the content of each pot. The notations are defined in the following tabulation:

| Notation | Content of Pot |
|---|---|
| Waukegan or Nicollet | Productive Minnesota soil |
| 0 D.M. (Soil) | 0% dredged material (100% marginal soil) |
| 1/3 D.M. | 1/3 dredged material and 2/3 marginal soil |
| 2/3 D.M. | 2/3 dredged material and 1/3 marginal soil |
| 1 D.M. | 100% dredged material (0% marginal soil) |

The sandy dredged material of the Minnesota and Mississippi treatments (Figures 14 through 17) produced less growth for both crops than the marginal or control soils. This lower production was not fully explained by the data but was attributed to the fertilizer treatment and water management.


Figure 12. Comparisons of plant (ryegrass) growth at second cutting for productive soils from Minnesota


Figure 13. Comparisons of plant (barley) growth at second harvest for productive soils from Minnesota

Table 15

Yields of Ryegrass Plants Grown on Soils and Dredged Material. Values are Averages for Five Growth Pots with Standard Errors as Indicated

| | | 1st cutting** (g/pot) | | 2nd cutting** (g/pot) | | 3rd cutting** (g/pot) | | Total |
|---|---|---|---|---|---|---|---|---|
| | | Mean* | s.e. | Mean* | s.e. | Mean* | s.e. | (g/pot) |
| Ala. | D.M. | 2.14 | 0.18 | 5.02 | 0.53 | 4.71 | 0.55 | 11.87 |
| | 2/3 D.M. | 0.99 | 0.02 | 3.14 | 0.18 | 3.11 | 0.37 | 7.24 |
| | 1/3 D.M. | 1.41 | 0.17 | 3.34 | 0.29 | 3.63 | 0.24 | 8.38 |
| | Soil | 0.27 | 0.03 | 0.49 | 0.14 | 0.40 | 0.11 | 1.16 |
| Conn. | D.M. | 7.30 | 0.48 | 10.23 | 1.16 | 6.29 | 0.68 | 23.82 |
| | 2/3 D.M. | 6.77 | 1.05 | 10.49 | 0.58 | 11.11 | 0.37 | 28.37 |
| | 1/3 D.M. | 6.45 | 0.78 | 9.31 | 0.66 | 10.32 | 0.57 | 26.07 |
| | Soil | 1.55 | 0.27 | 3.57 | 0.28 | 3.53 | 0.35 | 8.65 |
| Ill. | D.M. | 3.80 | 0.29 | 10.08 | 0.48 | 8.42 | 0.54 | 22.30 |
| | 2/3 D.M. | 3.45 | 0.11 | 8.61 | 0.39 | 8.44 | 0.52 | 20.50 |
| | 1/3 D.M. | 2.54 | 0.20 | 7.46 | 0.47 | 7.46 | 0.19 | 17.46 |
| | Soil | 1.40 | 0.13 | 3.29 | 0.19 | 2.39 | 0.18 | 7.08 |
| Mich. | D.M. | 6.49 | 0.45 | 12.36 | 0.38 | 8.98 | 0.70 | 27.83 |
| | 2/3 D.M. | 5.59 | 0.61 | 11.19 | 1.04 | 8.35 | 0.96 | 25.13 |
| | 1/3 D.M. | 5.10 | 0.38 | 9.50 | 0.62 | 7.86 | 0.44 | 22.46 |
| | Soil | 4.09 | 0.41 | 5.70 | 0.23 | 2.82 | 0.18 | 12.61 |
| Minn. | D.M. | 1.10 | 0.13 | 2.59 | 0.19 | 2.22 | 0.15 | 5.91 |
| | 2/3 D.M. | 3.71 | 0.29 | 6.97 | 0.21 | 6.10 | 0.30 | 16.78 |
| | 1/3 D.M. | 5.24 | 0.29 | 9.96 | 0.60 | 8.57 | 0.55 | 23.77 |
| | Soil | 5.27 | 0.40 | 12.27 | 0.61 | 11.59 | 0.92 | 29.13 |
| Miss. | D.M. | 0.41 | 0.03 | 1.13 | 0.12 | 0.96 | 0.09 | 2.50 |
| | 2/3 D.M. | 2.39 | 0.22 | 5.91 | 0.18 | 3.30 | 0.53 | 11.60 |
| | 1/3 D.M. | 3.55 | 0.13 | 7.20 | 0.38 | 4.35 | 0.41 | 15.10 |
| | Soil | 4.32 | 0.08 | 9.62 | 0.30 | 5.28 | 0.21 | 19.22 |
| N.J. | D.M. | 6.03 | 0.21 | 14.18 | 1.26 | 11.04 | 1.06 | 31.25 |
| | 2/3 D.M. | 6.40 | 0.65 | 13.07 | 1.12 | 10.62 | 0.55 | 30.09 |
| | 1/3 D.M. | 4.40 | 0.36 | 9.52 | 0.61 | 8.10 | 0.95 | 22.02 |
| | Soil | 1.72 | 0.09 | 3.32 | 0.40 | 2.43 | 0.18 | 7.47 |

* Yields for all pots were adjusted to that equivalent to 20 plants per pot.

** 1st cutting was made 38 days after planting. 2nd cutting was made 31 days after 1st cutting. 3rd cutting was made 25 days after 2nd cutting except for Conn. and Wauk. Soil (b) where 1st cutting was made 47 days after planting, 2nd cutting was made 31 days after 1st cutting, 3rd cutting was made 25 days after 2nd cutting.

Table 15 (concluded)

| | | 1st cutting** (g/pot) | | 2nd cutting** (g/pot) | | 3rd cutting** (g/pot) | | Total |
|---|---|---|---|---|---|---|---|---|
| | | Mean* | s.e. | Mean* | s.e. | Mean* | s.e. | (g/pot) |
| N.Y. | D.M. | 1.27 | 0.08 | 9.51 | 0.36 | 9.86 | 0.57 | 20.64 |
| | 2/3 D.M. | 1.66 | 0.37 | 7.65 | 0.79 | 7.41 | 0.47 | 16.72 |
| | 1/3 D.M. | 1.31 | 0.19 | 6.50 | 0.54 | 7.54 | 0.56 | 15.35 |
| | Soil | 0.51 | 0.09 | 1.91 | 0.21 | 9.93 | 0.20 | 4.35 |
| Ohio | D.M. | 6.16 | 0.39 | 12.93 | 0.69 | 11.06 | 1.02 | 30.15 |
| | 2/3 D.M. | 5.46 | 0.52 | 9.32 | 2.16 | 9.56 | 0.76 | 24.34 |
| | 1/3 D.M. | 4.52 | 0.21 | 7.95 | 0.42 | 6.79 | 0.62 | 19.26 |
| | Soil | 1.21 | 0.09 | 1.91 | 0.12 | 1.32 | 0.08 | 4.44 |
| S.C. | D.M. | 3.70 | 0.27 | 8.81 | 0.61 | 10.21 | 0.37 | 22.72 |
| | 2/3 D.M. | 2.90 | 0.35 | 7.54 | 0.63 | 9.05 | 0.64 | 19.49 |
| | 1/3 D.M. | 1.94 | 0.11 | 5.21 | 0.35 | 6.34 | 0.30 | 13.49 |
| | Soil | 0.34 | 0.05 | 1.57 | 1.00 | 0.45 | 0.09 | 2.36 |
| Wauk. (a) | Soil | 4.78 | 0.10 | 9.34 | 0.23 | 6.30 | 0.23 | 20.42 |
| Wauk. (b) | | 7.85 | 0.33 | 7.83 | 0.41 | 4.84 | 0.55 | 20.52 |
| Port B. | Soil | 3.94 | 0.21 | 9.69 | 0.60 | 8.36 | 0.38 | 21.99 |
| Nicol. | Soil | 2.09 | 0.12 | 6.63 | 0.26 | 6.09 | 0.26 | 14.81 |

Table 16

Yields of Barley Plants Grown on Soils and Dredged Material.

Values are Averages for Five Growth Pots with Standard Errors as Indicated

| | | 1st crop** (g/pot) | | 2nd crop** (g/pot) | | Total |
|---|---|---|---|---|---|---|
| | | Mean* | s.e. | Mean* | s.e. | (g/pot) |
| Ala. | D.M. | 2.85 | 0.52 | 0.35 | 0.08 | 3.20 |
| | 2/3 D.M. | 2.35 | 0.15 | 1.34 | 0.08 | 3.69 |
| | 1/3 D.M. | 2.57 | 0.22 | 1.48 | 0.16 | 4.05 |
| | Soil | 0.83 | 0.03 | 6.71 | 0.46 | 7.54 |
| Conn. | D.M. | 0.76 | 0.28 | 14.80 | 2.09 | 15.56 |
| | 2/3 D.M. | 0.72 | 0.34 | 16.25 | 0.42 | 16.97 |
| | 1/3 D.M. | 1.46 | 0.28 | 12.30 | 0.51 | 13.76 |
| | Soil | 4.05 | 0.37 | 8.50 | 0.85 | 12.55 |
| Ill. | D.M. | 5.63 | 0.33 | 18.07 | 0.96 | 23.7 |
| | 2/3 D.M. | 5.90 | 0.36 | 15.65 | 0.69 | 21.55 |
| | 1/3 D.M. | 5.37 | 0.35 | 12.00 | 0.55 | 17.37 |
| | Soil | 3.20 | 0.23 | 4.83 | 0.19 | 8.03 |
| Mich. | D.M. | 13.69 | 0.98 | 16.57 | 1.54 | 30.26 |
| | 2/3 D.M. | 10.66 | 0.43 | 14.63 | 1.00 | 25.29 |
| | 1/3 D.M. | 8.90 | 0.24 | 11.60 | 0.46 | 20.5 |
| | Soil | 5.55 | 0.30 | 3.32 | 0.45 | 8.87 |
| Minn. | D.M. | 2.66 | 0.20 | 4.68 | 0.58 | 7.34 |
| | 2/3 D.M. | 6.53 | 0.39 | 10.42 | 0.78 | 16.95 |
| | 1/3 D.M. | 8.98 | 0.33 | 13.35 | 0.72 | 22.33 |
| | Soil | 10.06 | 0.37 | 14.58 | 0.63 | 24.64 |
| Miss. | D.M. | 1.28 | 0.11 | 3.71 | 0.34 | 4.99 |
| | 2/3 D.M. | 4.63 | 0.33 | 6.74 | 0.60 | 11.37 |
| | 1/3 D.M. | 5.99 | 0.36 | 7.91 | 0.43 | 13.90 |
| | Soil | 6.91 | 0.23 | 10.03 | 0.58 | 16.94 |
| N.J. | D.M. | 9.62 | 1.64 | 17.04 | 0.90 | 26.66 |
| | 2/3 D.M. | 10.23 | 1.23 | 13.92 | 0.66 | 24.15 |
| | 1/3 D.M. | 3.75 | 0.59 | 12.50 | 1.23 | 16.25 |
| | Soil | 3.03 | 0.11 | 6.53 | 1.01 | 9.56 |

* Yields for all pots were adjusted to that equivalent to 10 plants per pot.

** 1st crop was harvested 38 days after planting. 2nd crop was harvested 47 days after planting.

Table 16 (concluded)

| | | 1st crop** (g/pot) | | 2nd crop** (g/pot) | | Total |
|---|---|---|---|---|---|---|
| | | Mean* | s.e. | Mean* | s.e. | (g/pot) |
| N.Y. | D.M. | 2.59 | 0.32 | 7.25 | 0.92 | 9.84 |
| | 2/3 D.M. | 2.46 | 0.18 | 8.23 | 2.14 | 10.69 |
| | 1/3 D.M. | 2.62 | 0.24 | 10.37 | 1.33 | 12.99 |
| | Soil | 1.21 | 0.05 | 3.40 | 0.44 | 4.61 |
| Ohio | D.M. | 9.77 | 0.63 | 13.40 | 1.12 | 23.17 |
| | 2/3 D.M. | 10.33 | 0.23 | 14.79 | 0.70 | 25.12 |
| | 1/3 D.M. | 7.44 | 0.15 | 10.79 | 0.39 | 18.23 |
| | Soil | 2.43 | 0.24 | 6.80 | 0.48 | 9.23 |
| S.C. | D.M. | 6.20 | 0.57 | 7.73 | 0.44 | 13.93 |
| | 2/3 D.M. | 3.95 | 0.31 | 7.16 | 0.66 | 11.11 |
| | 1/3 D.M. | 2.14 | 0.16 | 5.57 | 0.63 | 7.71 |
| | Soil | 1.11 | 0.09 | 2.69 | 0.39 | 3.80 |
| Wauk. | Soil | 7.03 | 0.25 | 12.32 | 0.44 | 19.35 |
| Port B. | Soil | 3.84 | 0.34 | 15.18 | 0.46 | 19.02 |
| Nicol. | Soil | 2.14 | 0.09 | 13.00 | 0.42 | 15.14 |


Figure 14. Comparisons of plant (ryegrass) growth at second cutting for dredged material, marginal soil, and their mixtures from Minnesota and productive soil from Minnesota


Figure 15. Comparisons of plant (ryegrass) growth at second cutting for dredged material, marginal soil, and their mixtures from Mississippi and productive soil from Minnesota


Figure 16. Comparisons of plant (barley) growth for dredged material, marginal soil, and their mixtures from Minnesota and productive soil from Minnesota

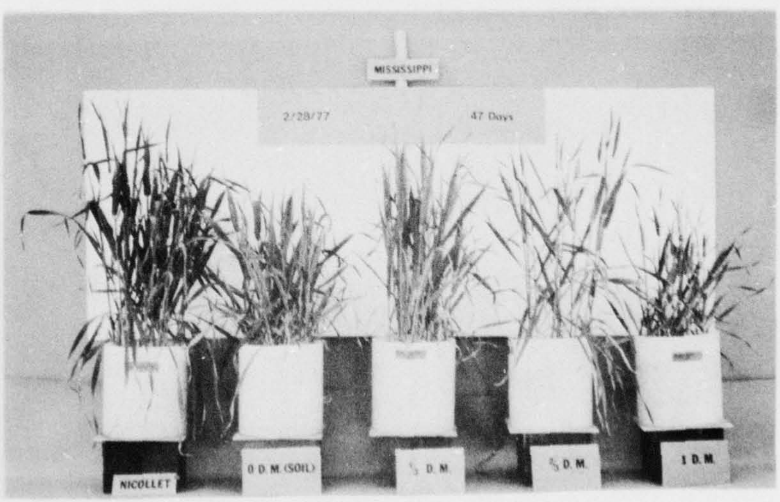


Figure 17. Comparisons of plant (barley) growth for dredged material, marginal soil, and their mixtures from Mississippi and productive soil from Minnesota


Figure 18. Comparisons of plant (ryegrass) growth at second cutting for dredged material, marginal soil, and their mixtures from Alabama and productive soil from Minnesota


Figure 19. Comparisons of plant (ryegrass) growth at second cutting for dredged material and its mixtures with marginal soil from Connecticut and productive soil from Minnesota


Figure 20. Comparisons of plant (ryegrass) growth at second cutting for dredged material, marginal soil, and their mixtures from South Carolina and productive soil from Minnesota

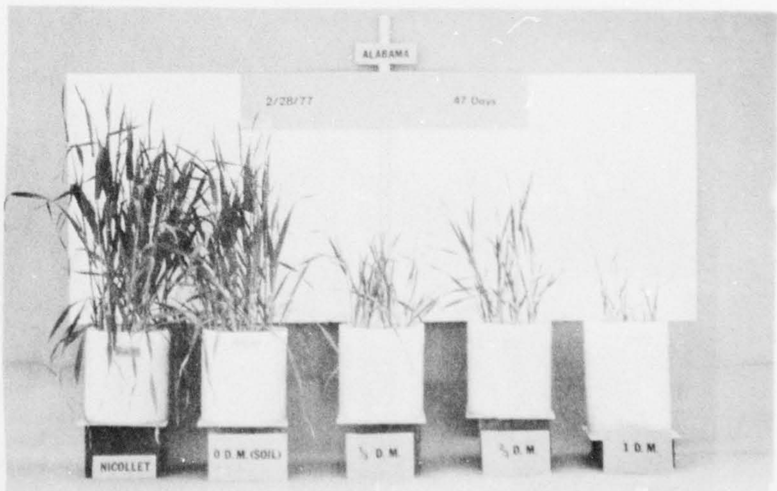


Figure 21. Comparisons of plant (barley) growth for dredged material, marginal soil, and their mixtures from Alabama and productive soil from Minnesota

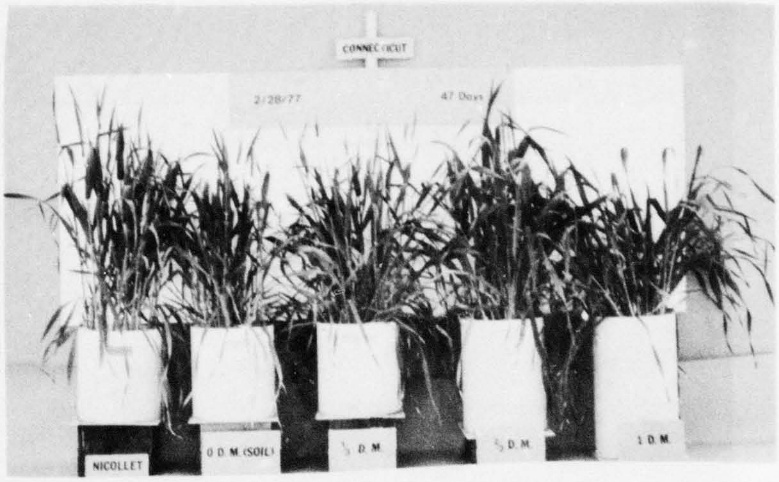


Figure 22. Comparisons of plant (barley) growth for dredged material, marginal soil, and their mixtures from Connecticut and productive soil from Minnesota

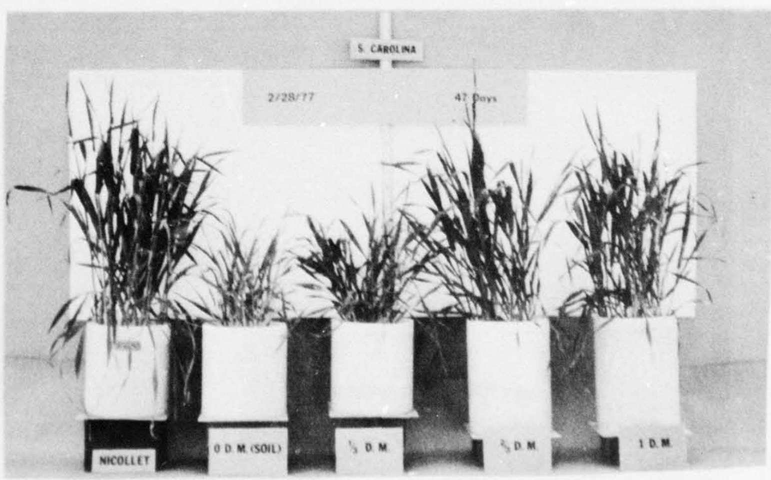


Figure 23. Comparisons of plant (barley) growth for dredged material, marginal soil, and their mixtures from South Carolina and productive soil from Minnesota


Figure 24. Comparisons of plant (ryegrass) growth at second cutting for dredged material, marginal soil, and their mixtures from Connecticut and productive soil from Minnesota


Figure 25. Comparisons of plant (ryegrass) growth at second cutting for dredged material, marginal soil, and their mixtures from New York and productive soil from Minnesota


Figure 26. Comparisons of plant (ryegrass) growth at second cutting for dredged material, marginal soil, and their mixtures from Ohio and productive soil from Minnesota


Figure 27. Comparisons of plant (ryegrass) growth at second cutting for dredged material, marginal soil, and their mixtures from Michigan and productive soil from Minnesota


Figure 28. Comparisons of plant (barley) growth for dredged material, marginal soil, and their mixtures from New York and productive soil from Minnesota


Figure 29. Comparisons of plant (barley) growth for dredged material, marginal soil, and their mixtures from Ohio and productive soil from Minnesota

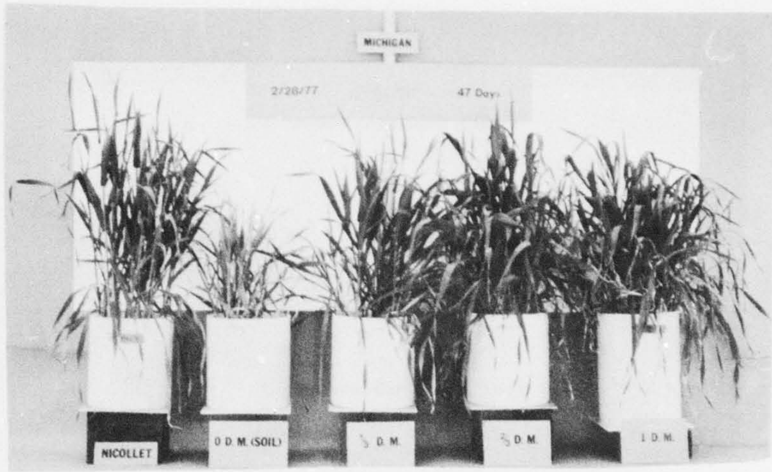


Figure 30. Comparisons of plant (barley) growth for dredged material, marginal soil, and their mixtures from Michigan and productive soil from Minnesota


Figure 31. Comparisons of plant (ryegrass) growth at second cutting for dredged material, marginal soil, and their mixtures from New Jersey and productive soil from Minnesota

AD-A061 298 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 13/3
THE AGRICULTURAL VALUE OF DREDGED MATERIAL.(U)
JUL 78 S C GUPTA, W E LARSON, R G GAST
UNCLASSIFIED WES-TR-D-78-36 NL

2 OF 2
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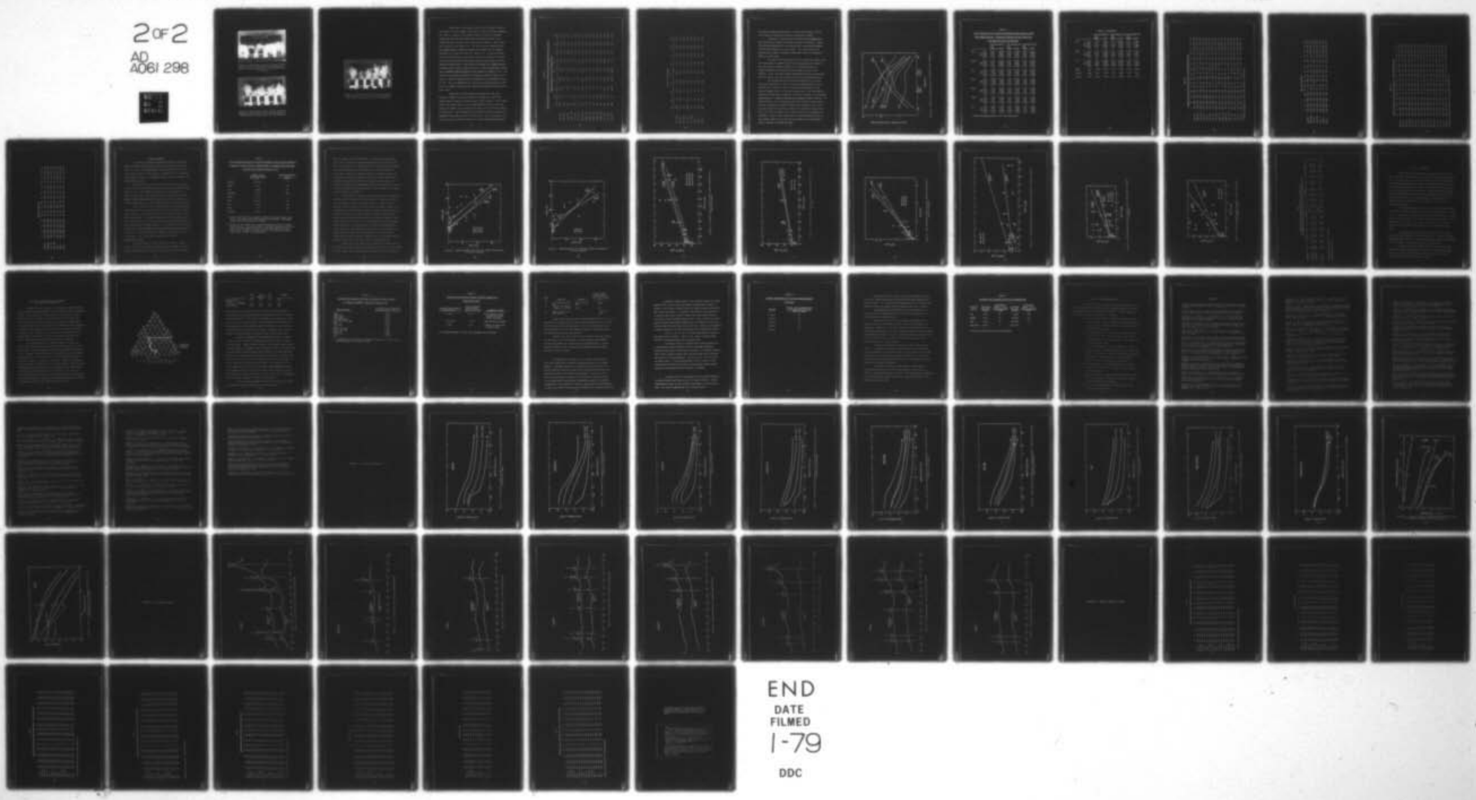

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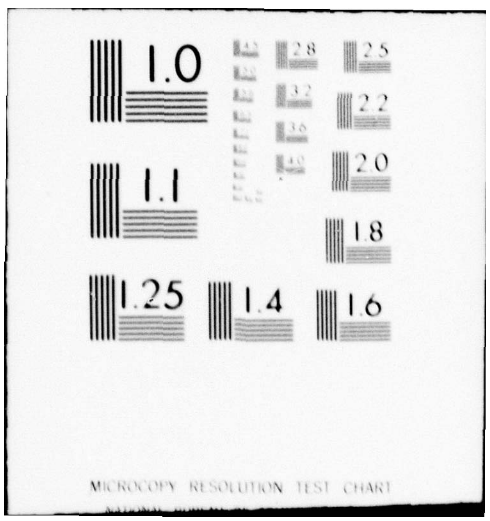
1.0
2.8
2.5
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MICROCOPY RESOLUTION TEST CHART

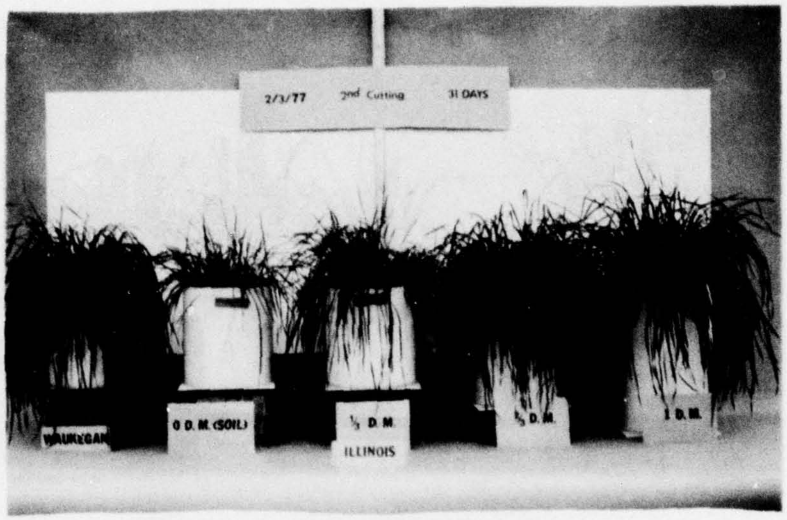


Figure 32. Comparisons of plant (ryegrass) growth at second cutting for dredged material, marginal soil, and their mixtures from Illinois and productive soil from Minnesota


Figure 33. Comparisons of plant (barley) growth for dredged material, marginal soil, and their mixtures from New Jersey and productive soil from Minnesota

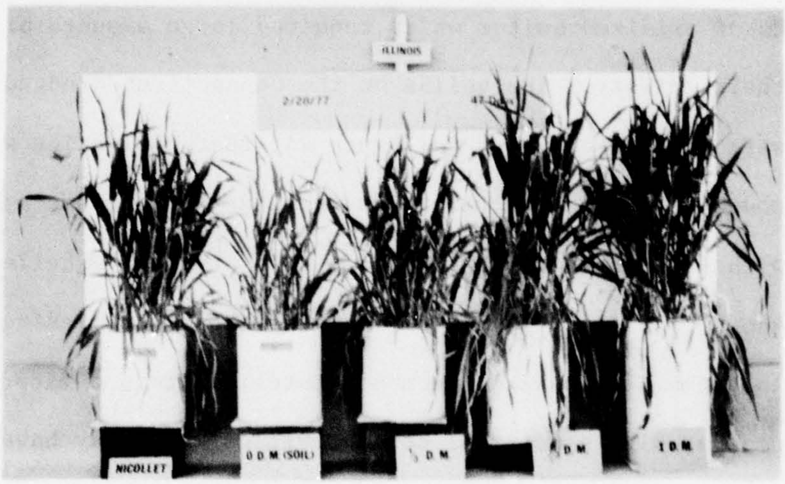


Figure 34. Comparisons of plant (barley) growth for dredged material, marginal soil, and their mixtures from Illinois and productive soil from Minnesota

Comparisons of the growth of both crops are shown in Figures 18 through 23 for the Alabama, Connecticut, and South Carolina treatments. The yields of ryegrass on the Alabama (Figures 18 and 21) treatments showed that they were better when mixed with dredged material or on dredged material alone than on the marginal soil; however, these results were reversed for the barley crop. The South Carolina (Figures 20 and 23) dredged material treatments showed better growth than the Alabama treatments but yielded less than the control soil. As noted previously, the three dredged materials presented in Figures 18 through 23 contained large amounts of oxidized sulfur which required large amounts of lime to neutralize their acidity. The yeilds on the Connecticut dredged material treatments were so low, as shown in Figure 24, that replanting with higher than recommended limestone additions was necessary to produce a crop. The replanting with adequate additions of limestone produced excellent plant growth, as shown in Figures 19 and 22 (marginal soil pot missing from Figure 19). Also, the Alabama and the South Carolina dredged material treatments had somewhat high electrical conductivities which may have affected plant growth.

Comparisons of plant growth for the New York, Ohio, and Michigan treatments are shown in Figures 25 through 30. These three dredged material samples contained slightly higher amounts of zinc, copper, nickel, and cadmium than the other dredged materials used in the study (Table 17); however, plant growth did not appear to be affected by uptake of these metals. The photographs show that plant growth was benefited by amendments with dredged material for both crops. The oil and grease content was high in the New York (Figures 25 and 28) dredged material which

Table 17

DTPA Extraction for 24 Hours of Initial Air-Dried Dredged Material and Soil

Samples Using a 1:5 Soil Solution Ratio

| | Fe | Mn | Zn | Cu | Pb | Ni | Cr | Cd | Hg |
|---|---|---|---|---|---|---|---|---|---|
| | ppm | | | | | | | | |
| Ala. DM | 1037 | 115 | 161.1 | 17.69 | 1.91 | 2.38 | 0.39 | 0.63 | 2.74 |
| Ala. Soil | 126 | 30 | 0.8 | 0.29 | 2.17 | 0.28 | 0.03 | 0.01 | 0.08 |
| Conn. DM | 1337 | 3 | 14.6 | 25.17 | 0.80 | 1.91 | 0.68 | 1.00 | 3.20 |
| Conn. Soil | 117 | 10 | 3.5 | 1.75 | 9.69 | 0.46 | 0.04 | 0.07 | 0.11 |
| Ill. DM | 623 | 194 | 12.1 | 7.01 | 10.01 | 4.13 | 0.44 | 0.27 | 1.49 |
| Ill. Soil | 56 | 78 | 2.4 | 0.67 | 2.12 | 0.50 | 0.12 | 0.06 | 0.00 |
| Mich. DM | 638 | 197 | 89.4 | 85.57 | 36.37 | 11.52 | 0.60 | 2.65 | 1.43 |
| Mich. Soil | 62 | 20 | 4.2 | 3.11 | 8.14 | 0.26 | 0.04 | 0.07 | 0.00 |
| Minn. DM | 105 | 30 | 3.5 | 0.93 | 1.16 | 0.37 | 0.08 | 0.18 | 0.04 |
| Minn. Soil | 352 | 306 | 6.5 | 5.32 | 5.47 | 4.33 | 0.62 | 0.40 | 0.97 |
| Miss. DM | 143 | 182 | 1.0 | 0.41 | 0.00 | 0.61 | 0.20 | 0.02 | 0.39 |
| Miss. Soil | 345 | 362 | 4.2 | 3.51 | 1.51 | 5.03 | 0.58 | 0.26 | 1.16 |
| N.J. DM | 1147 | 118 | 104.3 | 32.54 | 2.52 | 10.94 | 0.35 | 1.72 | 2.95 |
| N.J. Soil | 324 | 10 | 2.2 | 2.48 | 16.93 | 0.36 | 0.24 | 0.15 | 0.68 |
| N.Y. DM | 484 | 123 | 144.6 | 92.30 | 120.96 | 2.02 | 0.53 | 3.69 | 1.05 |

Table 17 (concluded)

| | Fe | Mn | Zn | Cu | Pb | Ni | Cr | Cd | Hg |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | ppm | | | | |
| N.Y. Soil | 396 | 23 | 9.2 | 2.02 | 15.18 | 1.76 | 0.14 | 0.35 | 0.72 |
| Ohio DM | 633 | 106 | 20.5 | 18.27 | 23.47 | 3.47 | 0.30 | 2.95 | 1.45 |
| Ohio Soil | 343 | 11 | 3.3 | 0.38 | 3.35 | 0.35 | 0.11 | 0.09 | 0.56 |
| S.C. DM | 1150 | 110 | 43.1 | 2.97 | 1.06 | 2.23 | 0.44 | 0.48 | 2.92 |
| S.C. Soil | 60 | 4 | 1.3 | 0.13 | 1.03 | 0.29 | 0.00 | 0.00 | 0.00 |
| Wauk. | 117 | 69 | 1.9 | 1.13 | 1.87 | 1.64 | 0.08 | 0.08 | 0.16 |
| Port B. | 193 | 92 | 1.7 | 1.20 | 2.42 | 2.25 | 0.21 | 0.13 | 0.37 |
| Nicol. | 286 | 178 | 1.9 | 2.32 | 2.61 | 4.99 | 0.41 | 0.27 | 0.72 |

could have increased growth variation, but yield data (Tables 15 and 16) at the end of the study did not show any restriction of growth.

Comparisons of plant growth for the New Jersey (misnamed Delaware) and Illinois treatments are shown in Figures 31 through 34. Adding fine-textured dredged material incorporated with coarse-textured marginal soil was highly beneficial to plant growth. Also, plants grown on the dredged material samples yielded more than plants grown on the productive Minnesota control soils.

The yield of the plants grown in the greenhouse was greater on the pure dredged material samples than on the pure marginal soils for seven of the cases studied, as shown in Figure 35. In these seven cases, the dredged material was fine-textured and the marginal soil was coarse-textured. In two cases where the pure dredged material was coarse-textured, yield was greater on the pure marginal soil than on the dredged material.

When dredged material was mixed with marginal soil, the plant yields were intermediate to those of either pure dredged material or pure marginal soil. In general, yields increased with the addition of fine-textured dredged material to the coarse-textured soils. The differences in yield were greatest upon the addition of the first increment of fine-textured dredged material. Complete yield data are presented in Tables 15 and 16. Increased yields on the fine-textured material were caused by either greater nutrient availabiltiy or greater available water contents or both. Optimal levels of nitrogen fertilizer and water were applied at frequent intervals in an effort to minimize their effects on plant growth throughout all treatments. However, these efforts were not fully demonstrated by data on the nitrogen (Table 18) and other nutrients (Tables 19 and 20; Appendix C, Tables C1 through C5) uptaken by plants.

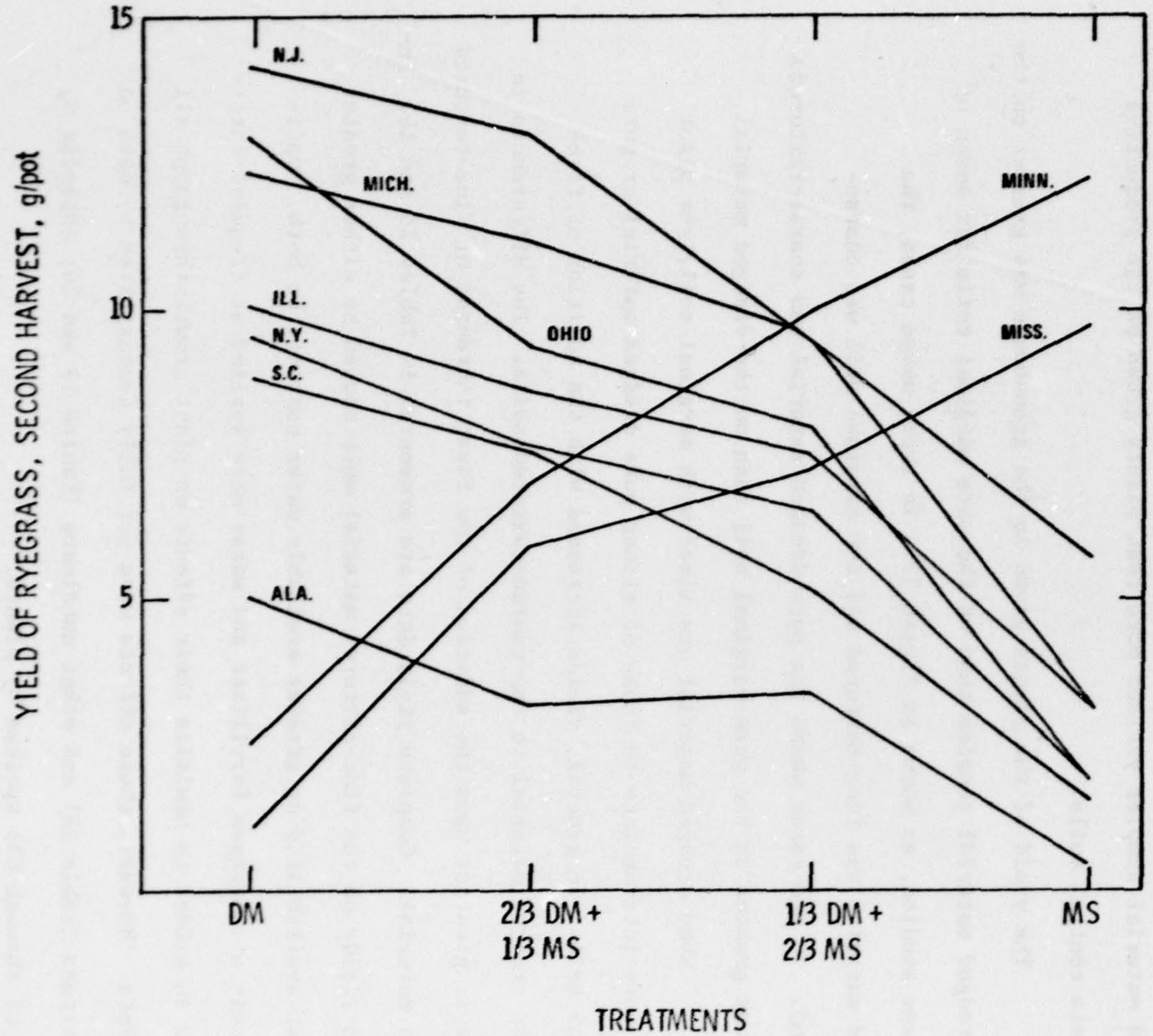


Figure 35. Yield of the second cutting of ryegrass for all treatments

Table 18

Total Nitrogen (% N) of Barley and Ryegrass Plants Grown on Soils and Dredged Material. Values are Averages for Two Growth Pots with Standard Errors as Indicated

| | | 2nd Crop Barley % N Mean | s.e. | 2nd Cutting Rye % N Mean | s.e. | 3rd Cutting Rye % N Mean | s.e. |
|---|---|---|---|---|---|---|---|
| Ala. | D.M. | 3.66 | 0.014 | 4.40 | 0.199 | 4.02 | 0.425 |
| | 2/3 D.M. | 4.30 | 0.029 | 4.66 | 0.316 | 4.92 | 0.020 |
| | 1/3 D.M. | 4.51 | 0.106 | 4.99 | 0.078 | 4.39 | 0.008 |
| | Soil | 4.37 | 0.213 | 7.26 | 0.523 | 6.19 | 0.156 |
| Conn. | D.M. | 4.31 | 0.409 | 4.93 | 0.070 | 3.65 | 0.019 |
| | 2/3 D.M. | 3.71 | 0.081 | 4.61 | 0.071 | 3.31 | 0.039 |
| | 1/3 D.M. | 3.73 | 0.300 | 4.83 | 0.129 | 3.14 | 0.343 |
| | Soil | 3.82 | 0.001 | 5.43 | 0.283 | 5.11 | 0.120 |
| Ill. | D.M. | 3.78* | 0.101 | 5.78 | 0.159 | 5.29 | 0.226 |
| | 2/3 D.M. | 3.82* | 0.127 | 4.89 | 0.219 | 4.91 | 0.261 |
| | 1/3 D.M. | 4.11* | 0.228 | 4.92 | 0.173 | 4.52 | 0.148 |
| | Soil | 4.64* | 0.183 | 5.67 | 0.251 | 6.81 | 0.325 |
| Mich. | D.M. | 3.82* | 0.192 | 4.99 | 0.058 | 4.65 | 0.145 |
| | 2/3 D.M. | 3.99* | 0.101 | 4.97 | 0.220 | 4.82 | 0.190 |
| | 1/3 D.M. | 4.23* | 0.162 | 4.86 | 0.199 | 4.68 | 0.187 |
| | Soil | 4.81* | 0.239 | 5.16 | 0.322 | 6.73 | 0.522 |
| Minn. | D.M. | 4.35 | 0.127 | 4.62 | 0.255 | 4.95 | 0.078 |
| | 2/3 D.M. | 4.35 | 0.168 | 5.06 | 0.155 | 5.17 | 0.103 |
| | 1/3 D.M. | 4.00 | 0.058 | 4.56 | 0.415 | 4.40 | 0.323 |
| | Soil | 3.65 | 0.055 | 5.18 | 0.105 | 4.57 | 0.153 |
| Miss. | D.M. | 4.80 | 0.242 | 7.17 | 0.234 | 7.25 | 0.018 |
| | 2/3 D.M. | 4.20 | 0.156 | 4.77 | 0.183 | 6.86 | 0.385 |
| | 1/3 D.M. | 3.76 | 0.163 | 5.00 | 0.158 | 5.60 | 0.273 |
| | Soil | 3.78 | 0.294 | 4.71 | 0.195 | 5.48 | 0.225 |
| N.J. | D.M. | 4.08 | 0.150 | 4.64 | 0.582 | 4.24 | 0.665 |
| | 2/3 D.M. | 4.00 | 0.385 | 4.55 | 0.285 | 4.37 | 0.284 |
| | 1/3 D.M. | 4.00 | 0.196 | 4.88 | 0.064 | 5.30 | 0.310 |
| | Soil | 3.99 | 0.134 | 6.79 | 0.101 | 6.13 | 0.689 |

* These values are averages of all five growth pots.

Table 18 (concluded)

| | | 2nd Crop Barley % N Mean | s.e. | 2nd Cutting Rye % N Mean | s.e. | 3rd Cutting Rye % N Mean | s.e. |
|---|---|---|---|---|---|---|---|
| N.Y. | D.M. | 3.75 | 0.541 | 4.72 | 0.068 | 4.29 | 0.284 |
| | 2/3 D.M. | 4.15 | 0.135 | 4.75 | 0.251 | 4.33 | 0.207 |
| | 1/3 D.M. | 3.77 | 0.102 | 5.04 | 0.020 | 4.57 | 0.160 |
| | Soil | 4.75 | 0.040 | 5.24 | 0.154 | 4.84 | 0.098 |
| Ohio | D.M. | 4.52 | 0.035 | 4.33 | 0.082 | 4.36 | 0.173 |
| | 2/3 D.M. | 4.03 | 0.368 | 5.01 | 0.416 | 4.54 | 0.274 |
| | 1/3 D.M. | 4.23 | 0.254 | 5.15 | 0.162 | 4.93 | 0.091 |
| | Soil | 3.72 | 0.209 | 6.41 | 0.517 | 5.61 | 0.129 |
| S.C. | D.M. | 4.18 | 0.007 | 4.78 | 0.108 | 4.34 | 0.315 |
| | 2/3 D.M. | 4.02 | 0.340 | 4.60 | 0.093 | 4.41 | 0.155 |
| | 1/3 D.M. | 4.89 | 0.030 | 4.60 | 0.161 | 4.41 | 0.310 |
| | Soil | 5.69 | 0.456 | 7.80 | 0.244 | 7.56 | 0.955 |
| Wauk. | Soil | 4.13* | 0.084 | 4.97 | 0.198 | 4.88 | 0.082 |
| Port B. | Soil | 3.94 | 0.045 | 5.25 | 0.284 | 5.12 | 0.165 |
| Nicol. | Soil | 4.22* | 0.094 | 5.11 | 0.163 | 4.69 | 0.067 |

Table 19

Elemental Analysis of First Crop Barley. Values Expressed as µg/g

| | P | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ala. DM | 1657 | 60055 | 5572 | 5680 | 64 | 124 | 23627 | 273 | 188.6 | 14.7 | 151.6 | 3.6 | 1.82 | 1.77 | 0.70 |
| Ala. Soil | 464 | 17431 | 5992 | 4344 | 37 | 61 | 620 | 73 | 11.9 | 4.3 | 4.1 | 2.0 | 1.08 | 0.95 | 0.16 |
| Conn. DM | 1646 | 22312 | 2064 | 4670 | 66 | 515 | 1041 | 60 | 24.5 | 6.9 | 10.3 | 22.5 | 1.54 | 0.70 | 0.76 |
| Conn. Soil | 4402 | 53030 | 11016 | 9607 | 124 | 217 | 499 | 31 | 45.8 | 12.7 | 7.2 | 12.9 | 1.31 | 0.99 | 0.64 |
| Ill. DM | 1656 | 24740 | 23088 | 7798 | 4 | 102 | 5488 | 160 | 63.4 | 7.1 | 27.2 | 3.7 | 1.92 | 0.77 | 0.29 |
| Ill. Soil | 3356 | 64824 | 14267 | 4712 | 28 | 101 | 446 | 57 | 56.4 | 14.2 | 9.7 | 2.7 | 1.36 | 0.81 | 0.27 |
| Mich. DM | 4762 | 31098 | 16749 | 4920 | 8 | 113 | 7818 | 174 | 137.0 | 20.1 | 18.8 | 2.3 | 1.44 | 0.00 | 1.64 |
| Mich. Soil | 6090 | 35445 | 9172 | 7490 | 61 | 110 | 496 | 34 | 44.1 | 10.8 | 15.6 | 3.8 | 1.15 | 0.03 | 0.43 |
| Minn. DM | 1647 | 29225 | 24706 | 5837 | 3 | 101 | 2069 | 207 | 46.7 | 13.1 | 18.2 | 3.7 | 1.85 | 0.86 | 1.41 |
| Minn. Soil | 2296 | 52815 | 19137 | 4936 | 57 | 150 | 2021 | 60 | 37 | 8.8 | 11.4 | 4.2 | 1.44 | 0.95 | 0.62 |
| Miss. DM | 1146 | 44047 | 16974 | 4631 | 20 | 137 | 1025 | 186 | 26 | 8.8 | 12.9 | 4.2 | 1.56 | 33.01 | 0.25 |
| Miss. Soil | 3173 | 57965 | 17489 | 4084 | 67 | 145 | 1289 | 57 | 41.3 | 10.1 | 12.7 | 3.4 | 1.46 | 0.69 | 0.72 |
| N.J. DM | 4776 | 56383 | 11262 | 7250 | 70 | 271 | 792 | 90 | 187.1 | 13.7 | 26.8 | 26.1 | 1.94 | 1.07 | 1.38 |
| N.J. Soil | 4736 | 21205 | 14612 | 13848 | 328 | 290 | 1387 | 128 | 34.8 | 13.1 | 15.9 | 25.6 | 1.59 | 1.16 | 0.50 |
| N.Y. DM | 1465 | 45275 | 19491 | 4921 | 20 | 93 | 4594 | 190 | 128.8 | 22.6 | 28.7 | 3.1 | 1.08 | 0.83 | 1.98 |
| N.Y. Soil | 1611 | 49907 | 7293 | 6716 | 31 | 103 | 273 | 151 | 67.6 | 9.8 | 9.6 | 5.2 | 0.76 | 0.00 | 1.13 |

* Values are averages of analysis of five replicate treatment pots.

Table 19 (concluded)

| | P | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ohio DM | 5198 | 42779 | 13962 | 4599 | 7 | 102 | 3990 | 94 | 79.4 | 9.7 | 15.1 | 6.2 | 1.53 | 0.00 | 5.04 |
| Ohio Soil | 1916 | 54631 | 7613 | 6941 | 36 | 133 | 198 | 112 | 48.6 | 6.8 | 9.2 | 2.4 | 0.90 | 0.00 | 0.74 |
| S.C. DM | 1871 | 71523 | 8149 | 4455 | 80 | 152 | 19732 | 259 | 151.8 | 9.7 | 82.1 | 2.7 | 1.31 | 1.07 | 0.81 |
| S.C. Soil | 428 | 16763 | 6031 | 3432 | 13 | 52 | 587 | 38 | 13.8 | 2.1 | 5.3 | 0.9 | 0.61 | 1.04 | 0.12 |
| Wauk. | 2086 | 43115 | 17153 | 4467 | 30 | 131 | 707 | 97 | 26.9 | 6.9 | 12.6 | 4.0 | 1.31 | 1.12 | 0.49 |
| Port B. | 2164 | 73840 | 17610 | 4115 | 14 | 111 | 335 | 186 | 28.7 | 7.7 | 9.7 | 3.8 | 0.99 | 0.89 | 0.55 |
| Nicol. | 2012 | 62522 | 17579 | 4946 | 11 | 98 | 815 | 89 | 40.8 | 9.3 | 14.4 | 5.0 | 2.02 | 1.03 | 0.59 |

Table 20

Elemental Analysis of First Cutting Ryegrass.* Values Expressed as $\mu g/g$

| | P | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ala. DM | 2055 | 66293 | 4541 | 4368 | 53 | 142 | 10331 | 234 | 206.2 | 26.0 | 133.3 | 6.2 | 4.62 | 2.22 | 0.52 |
| Ala. Soil | 952 | 37409 | 11928 | 6585 | 95 | 127 | 623 | 145 | 46.5 | 15.3 | 13.2 | 9.4 | 4.42 | 0.69 | 0.26 |
| Conn. DM | 3424 | 51255 | 3614 | 5278 | 129 | 777 | 2750 | 60 | 56.2 | 17.2 | 19.9 | 32.3 | 2.13 | 1.25 | 0.38 |
| Conn. Soil | 3593 | 30334 | 11283 | 9687 | 167 | 258 | 1968 | 42 | 49.5 | 17.9 | 13.2 | 11.5 | 1.76 | 1.00 | 0.50 |
| Ill. DM | 2667 | 27497 | 13370 | 4746 | 92 | 187 | 14123 | 97 | 81.1 | 22.2 | 28.4 | 3.5 | 2.18 | 0.68 | 0.19 |
| Ill. Soil | 2569 | 50243 | 14355 | 5363 | 42 | 123 | 1627 | 71 | 60.9 | 15.8 | 15.0 | 3.2 | 1.89 | 0.75 | 0.31 |
| Mich. DM | 6416 | 27948 | 10493 | 4314 | 32 | 140 | 12843 | 217 | 164.0 | 32.4 | 35.1 | 3.0 | 8.95 | 0.00 | 1.02 |
| Mich. Soil | 6195 | 40133 | 8215 | 6143 | 85 | 148 | 462 | 44 | 64.7 | 15.9 | 16.0 | 4.8 | 2.12 | 0.05 | 0.59 |
| Minn. DM | 1879 | 38261 | 23965 | 4069 | 11 | 119 | 2931 | 230 | 65.1 | 18.5 | 20.3 | 2.7 | 3.03 | 0.55 | 1.22 |
| Minn. Soil | 2339 | 57686 | 12608 | 3804 | 42 | 130 | 3655 | 48 | 37.3 | 11.3 | 14.7 | 3.7 | 1.99 | 0.79 | 0.39 |
| Miss. DM | 828 | 41397 | 18478 | 3802 | 44 | 113 | 859 | 215 | 43.6 | 12.5 | 26.5 | 6.2 | 4.47 | 4.09 | 0.12 |
| Miss. Soil | 2761 | 60893 | 12642 | 3607 | 50 | 134 | 2352 | 50 | 41.6 | 15.0 | 15.0 | 3.2 | 3.32 | 6.65 | 0.44 |
| N.J. DM | 4295 | 58465 | 7140 | 5304 | 100 | 342 | 1174 | 134 | 173.9 | 20.6 | 31.8 | 26.2 | 5.15 | 1.11 | 0.94 |
| N.J. Soil | 5183 | 21356 | 7838 | 7875 | 222 | 438 | 1833 | 159 | 38.6 | 19.1 | 23.1 | 22.6 | 1.75 | 1.40 | 0.40 |
| N.Y. DM | 1892 | 53465 | 14722 | 2651 | 32 | 116 | 3259 | 184 | 152.4 | 38.0 | 38.3 | 1.6 | 2.28 | 0.72 | 0.52 |
| N.Y. Soil | 1584 | 32919 | 10013 | 7097 | 22 | 104 | 205 | 138 | 69.3 | 12.2 | 19.7 | 3.5 | 1.81 | 0.00 | 0.64 |

* Values are averages of analysis of five replicate treatment pots.

Table 20 (concluded)

| | P | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ohio DM | 6143 | 46426 | 8481 | 3419 | 33 | 147 | 4651 | 89 | 87.8 | 17.5 | 21.7 | 6.5 | 2.17 | 0.00 | 2.60 |
| Ohio Soil | 2126 | 35816 | 8845 | 7630 | 38 | 122 | 856 | 70 | 73.8 | 9.0 | 19.2 | 4.1 | 1.10 | 0.00 | 0.50 |
| S.C. DM | 2200 | 64804 | 6264 | 3993 | 72 | 143 | 8106 | 192 | 85.0 | 17.4 | 99.8 | 4.5 | 1.42 | 0.87 | 0.25 |
| S.C. Soil | 753 | 30851 | 11579 | 6120 | 35 | 102 | 807 | 88 | 35.8 | 5.9 | 18.9 | 1.5 | 1.64 | 2.87 | 0.23 |
| Wauk. | 2049 | 55051 | 13718 | 4064 | 51 | 128 | 2608 | 73 | 31.6 | 9.4 | 17.5 | 4.1 | 1.88 | 0.94 | 0.33 |
| Port B. | 1698 | 63879 | 15225 | 4034 | 27 | 119 | 801 | 150 | 42.4 | 11.4 | 15.8 | 4.3 | 1.84 | 1.19 | 0.36 |
| Nicol. | 1523 | 60284 | 15823 | 4116 | 17 | 102 | 1260 | 58 | 46.2 | 10.3 | 16.3 | 3.5 | 2.5 | 0.72 | 0.64 |

## Elemental Analyses

In general, the elemental composition values of the plants were in the normal ranges found in grasses but were not up to levels likely to be toxic for plant growth, as shown in Tables 18 and 21 for some of the treatments (entire data set in Appendix C). The phosphorus concentrations in many of the samples of plant tissue were unusually low.

### Heavy metals of plants

Analyses of plant tissue as shown in Tables 19 and 20 demonstrates that with the possible exception of boron in the Alabama dredged material, none of the element concentrations were high enough to be toxic to plant growth. The boron contents of the ryegrass and barley grown on Alabama dredged material were close to 150 μg/g, which is considered a borderline toxic level by Melsted (1973), as shown in Table 21.

Copper contents of the ryegrass and barley were within normal ranges (Melsted 1973) for plants grown under field conditions. However, nickel, chromium, and cadmium contents of the ryegrass and barley were above normal ranges. The cadmium concentrations in the plants exceeded the tolerance level of 3.0 μg/g for some of the treatments when grown on the New York and Ohio dredged material. Zinc concentrations in the plants grown on fine-textured dredged material exceeded the maximum normal level of 150 μg/g. Lead concentrations in a number of treatments exceeded 5 μg/g, which is the upper limit of normal plant tolerance.

### Heavy metals of soils

The concentrations of zinc, copper, and nickel in dredged material can be used to predict the uptake of these elements by plants grown on dredged material. However, the cadmium content of the plants

Table 21

Average Composition Range for Selected Agronomic Crops, and (the Authors') Suggested Tolerance Levels of Heavy Metals in Agronomic Crops when Used for Monitoring Purposes (Melsted, 1973)

| | Common Average Composition Range* µg/g | Suggested Tolerance Level** µg/g |
|---|---|---|
| Cadmium | 0.05-0.20 | 3 |
| Copper | 3-40 | 150 |
| Iron | 20-300 | 750 |
| Manganese | 15-150 | 300 |
| Nickel | 0.1-1.0 | 3 |
| Lead | 0.1-5.0 | 10 |
| Zinc | 15-150 | 300 |
| Boron | 7-75 | 150 |
| Chromium | 0.1-0.5 | 2 |

* Average values for corn, soybeans, alfalfa, red clover, wheat, oats, barley, and grasses grown under normal soil conditions. Greenhouse values, both soil and solution, omitted.

** Values for corn leaves at or opposite and below ear level at tassel stage, soybeans - the youngest mature leaves and petroles on the plant after first pod formation, legumes - upper stem cuttings in early flower stage, cereals, the whole plants at boot stage, and grasses - whole plants at early hay cutting stage.

was not related to the concentrations of cadmium by DTPA extraction. Zinc, copper, nickel, and cadmium concentrations extractable with DTPA were usually higher in the dredged material from Michigan, Ohio, and New York than dredged material from other sites, as shown in Table 17. Zinc, copper, nickel, and cadmium contents of the plants grown in the greenhouse on these three treatments were usually higher when grown on the pure dredged material than on the associated pure marginal soil. Therefore, the materials from Michigan, Ohio, and New York were selected to relate the heavy metal concentrations in the treatments to the uptake of heavy metals by the plants.

Plant uptake of zinc was linearly related to the concentration of DTPA-extractable zinc in all three cuttings of ryegrass, as shown in Figure 36, and for barley, as shown in Figure 37. Copper content of both the ryegrass and barley at all harvests was linearly related to the concentration of DTPA-extractable copper, as shown in Figures 38 and 39. The nickel content of ryegrass was linearly related to the amount of nickel extracted with DTPA (Figure 40), but the nickel content of barley was not significantly related to the concentration of DTPA-extractable nickel (Figure 41). The concentration of cadmium extracted with DTPA from soil was not a good indicator of the content of cadmium in plants. Cadmium uptake by plants was not significantly correlated with the concentration of DTPA-extractable cadmium in any of the ryegrass harvests (Figure 42), and only in the first crop of barley (Figure 43).

Table 22 gives the regression and correlation coefficients and F-statistics for plant uptake versus initial availability of soil nutrients for zinc, copper, nickel, and cadmium, as shown in Figures 36 through 43.

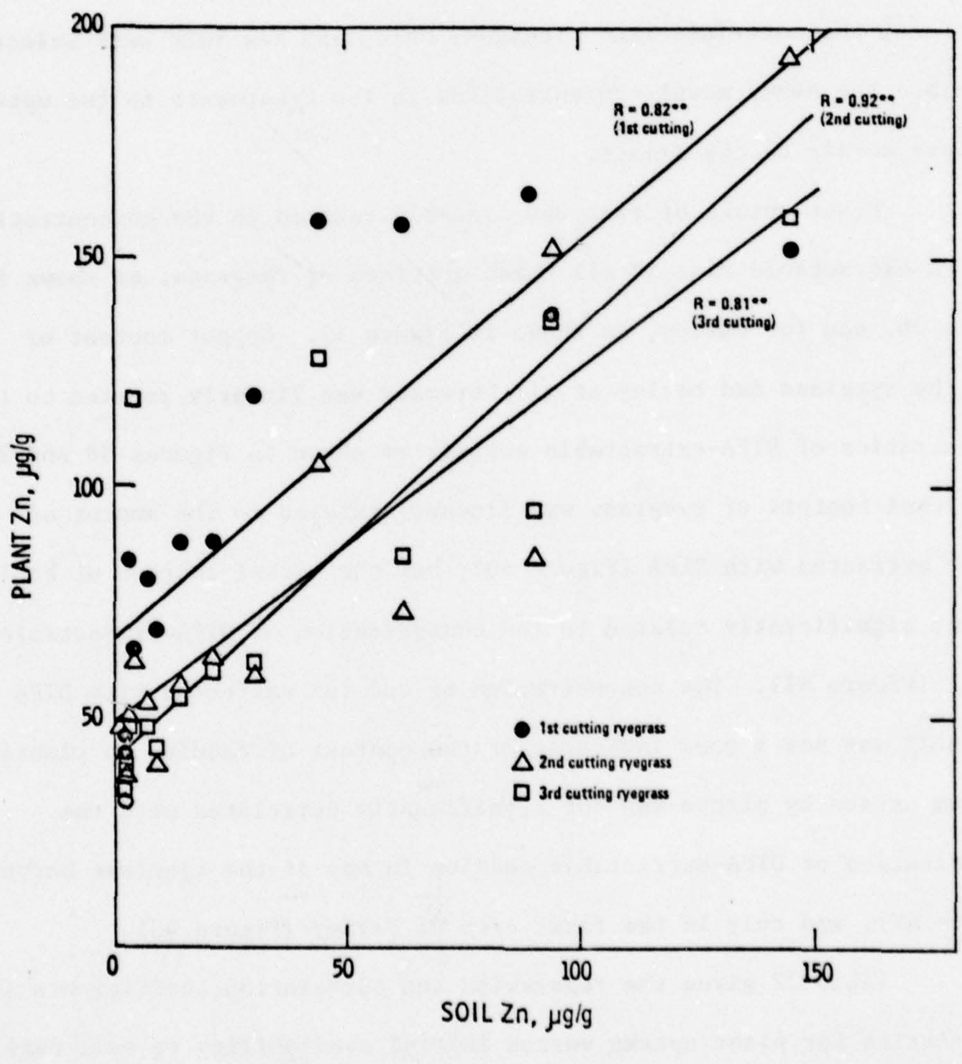


Figure 36. DTPA-extractable zinc from soil versus concentration of zinc in ryegrass

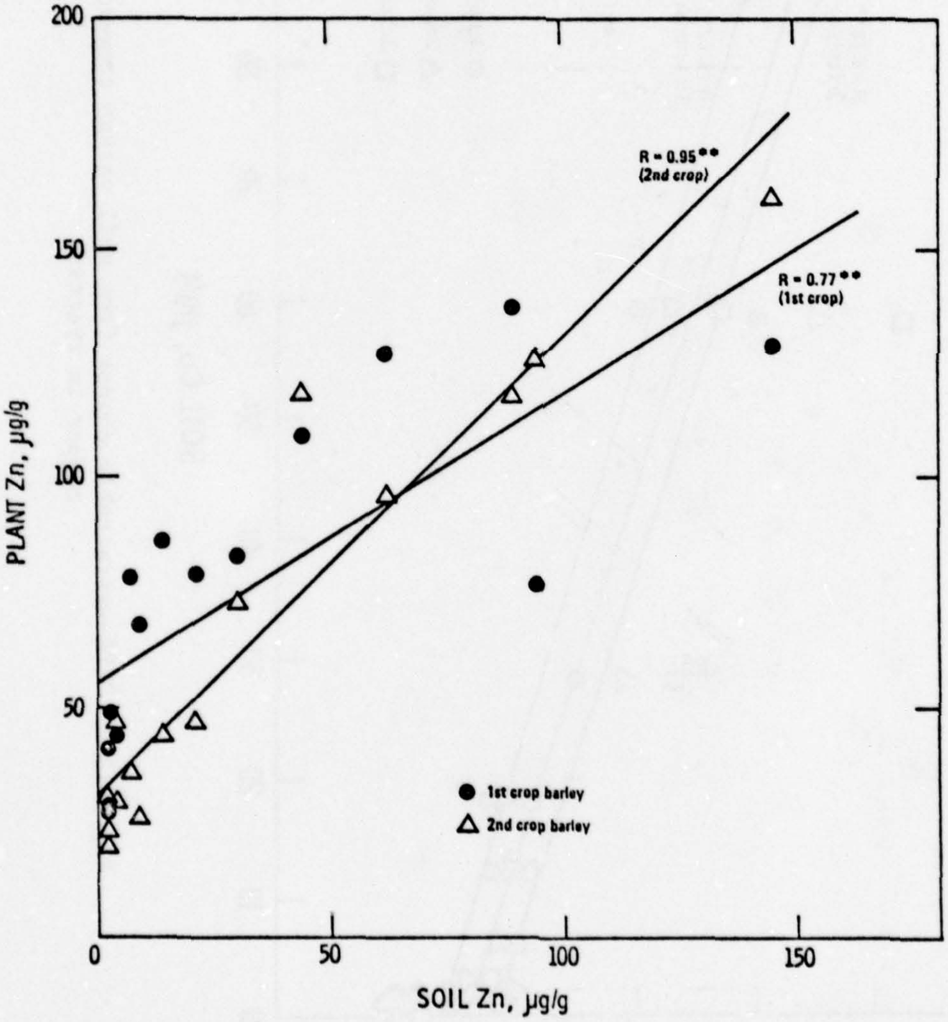


Figure 37. DTPA-extractable zinc from soil versus concentration of zinc in barley

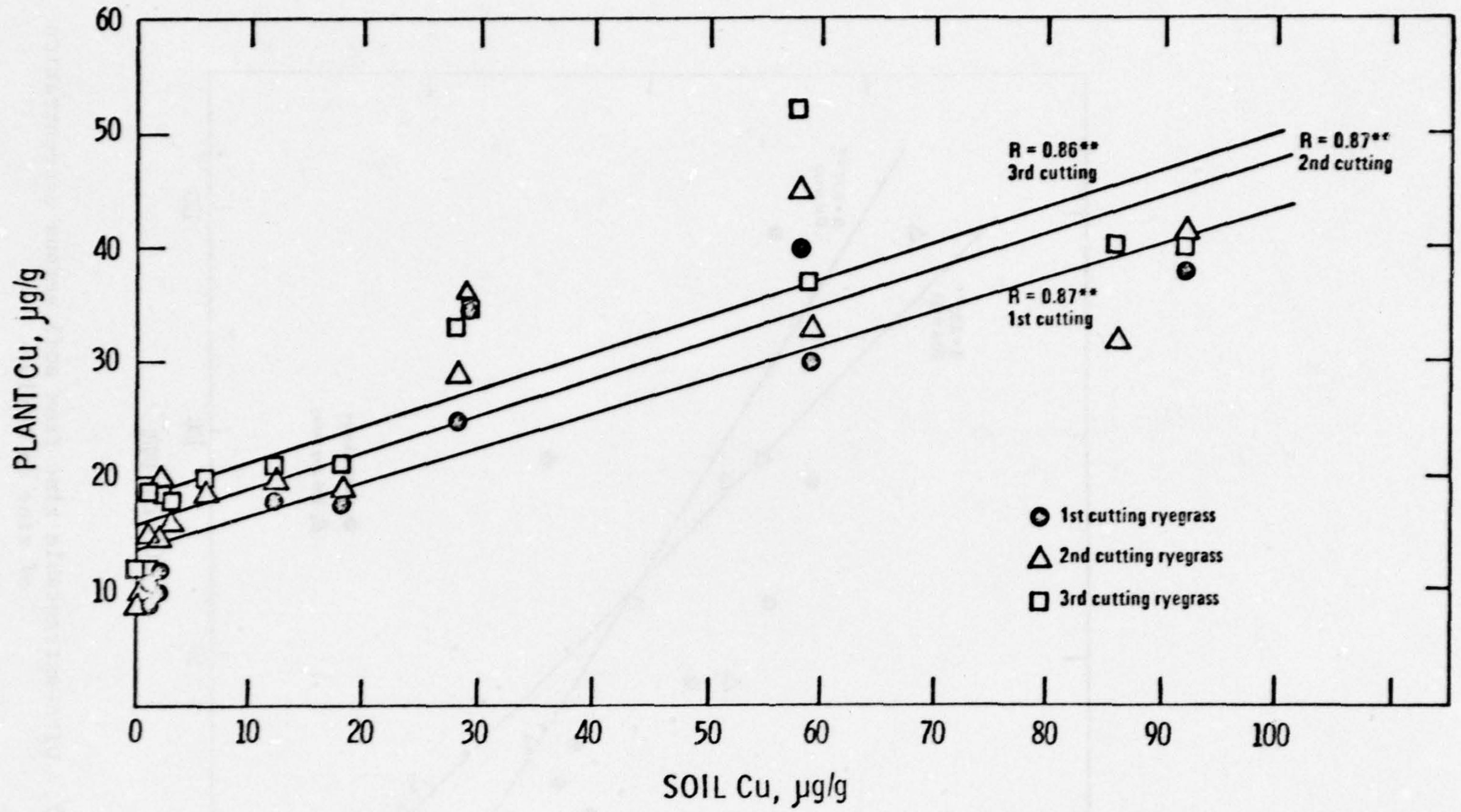


Figure 38. DTPA-extractable copper from soil versus concentration of copper in ryegrass

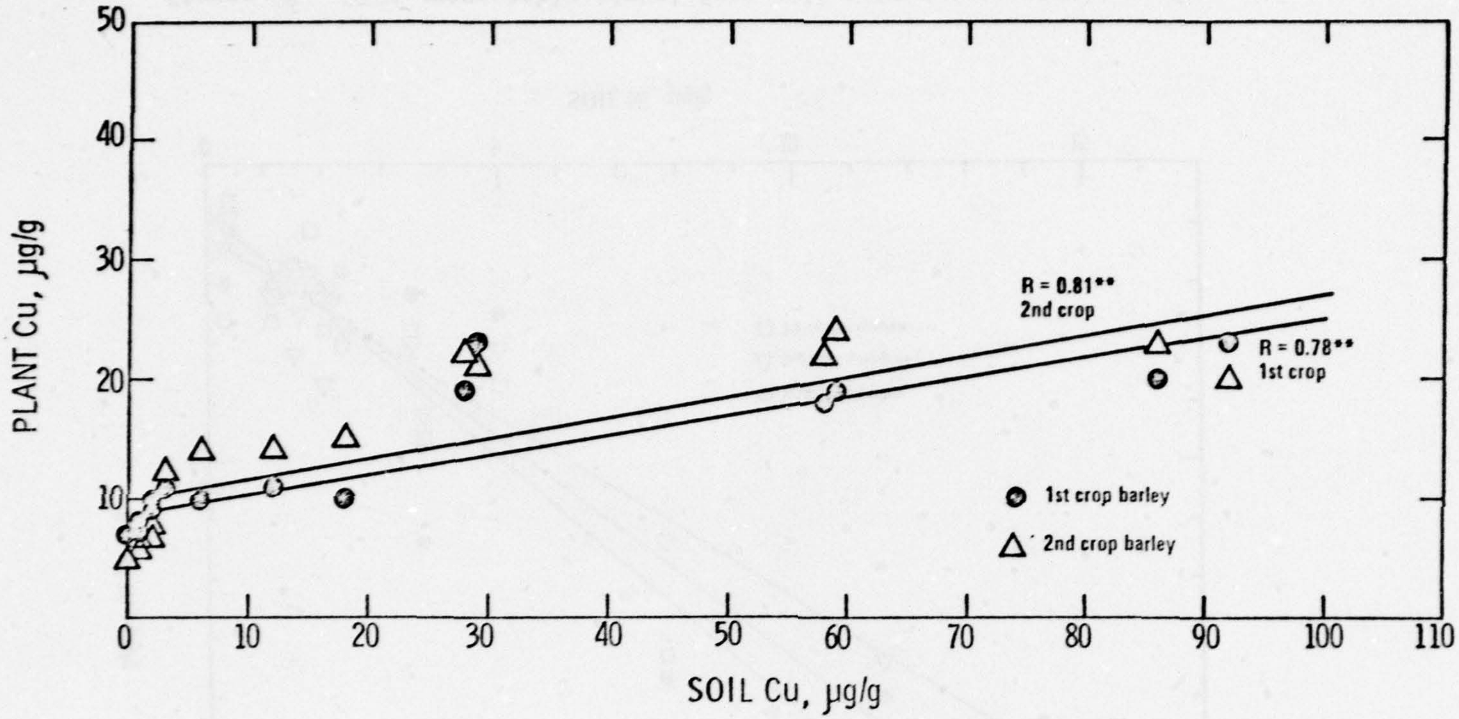


Figure 39. DTPA-extractable copper from soil versus concentration of copper in barley

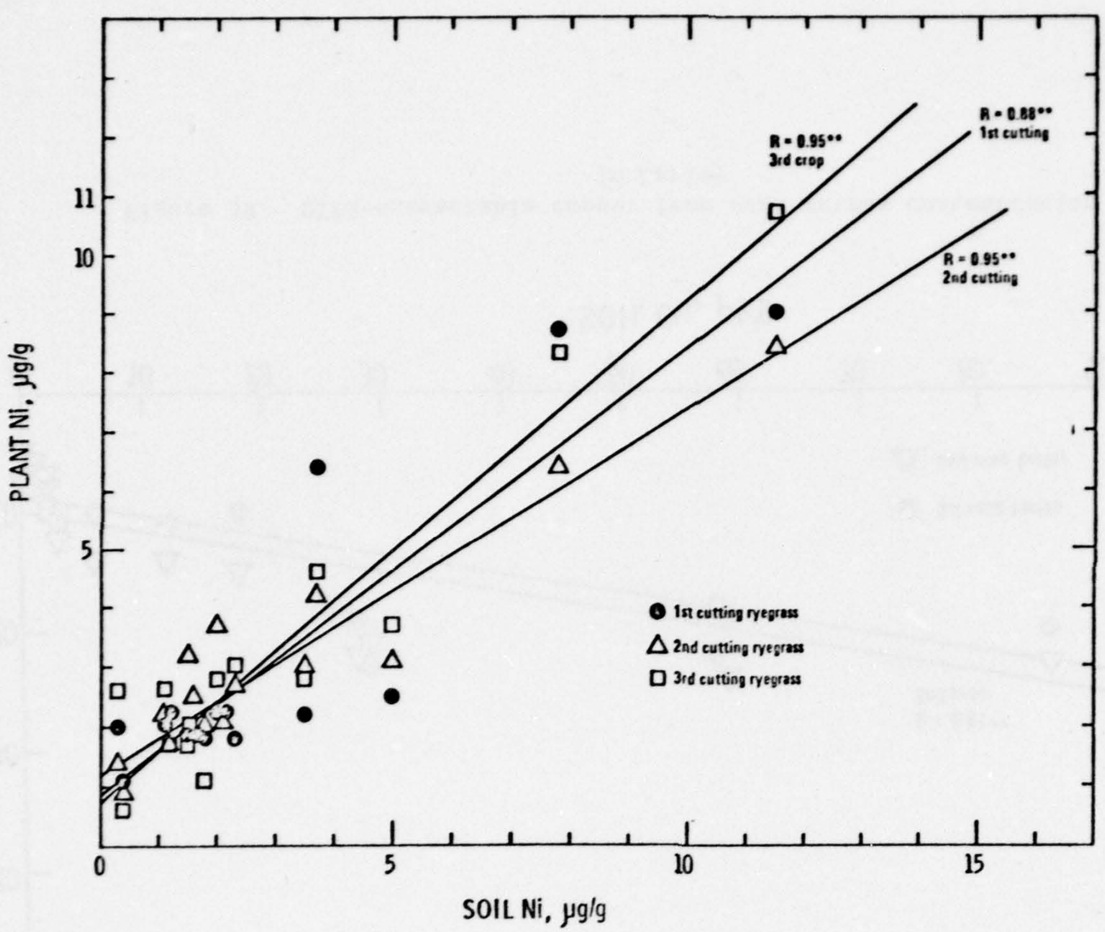


Figure 40. DTPA-extractable nickel from soil versus concentration of nickel in ryegrass

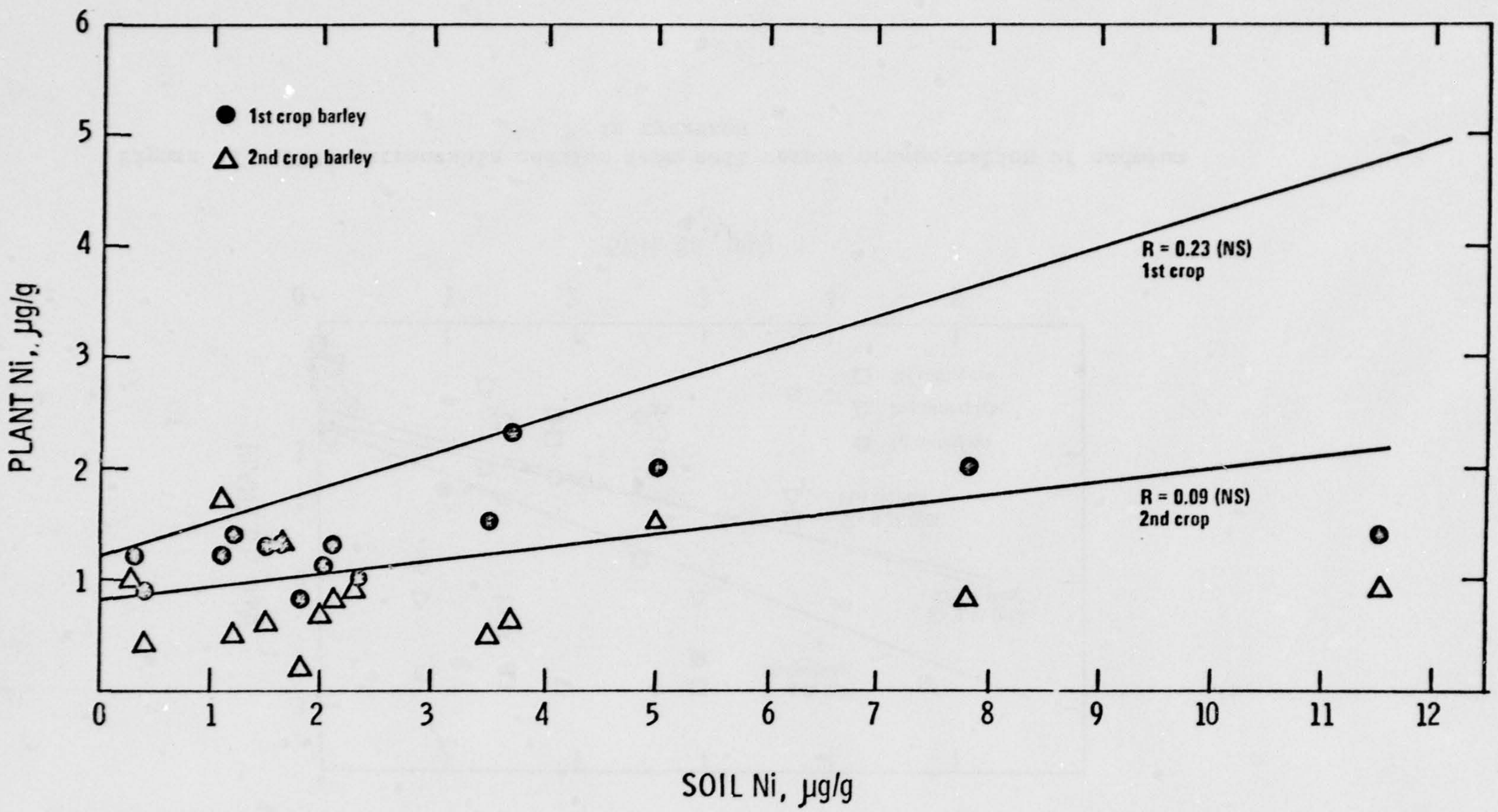


Figure 41. DTPA-extractable nickel from soil versus concentration of nickel in barley

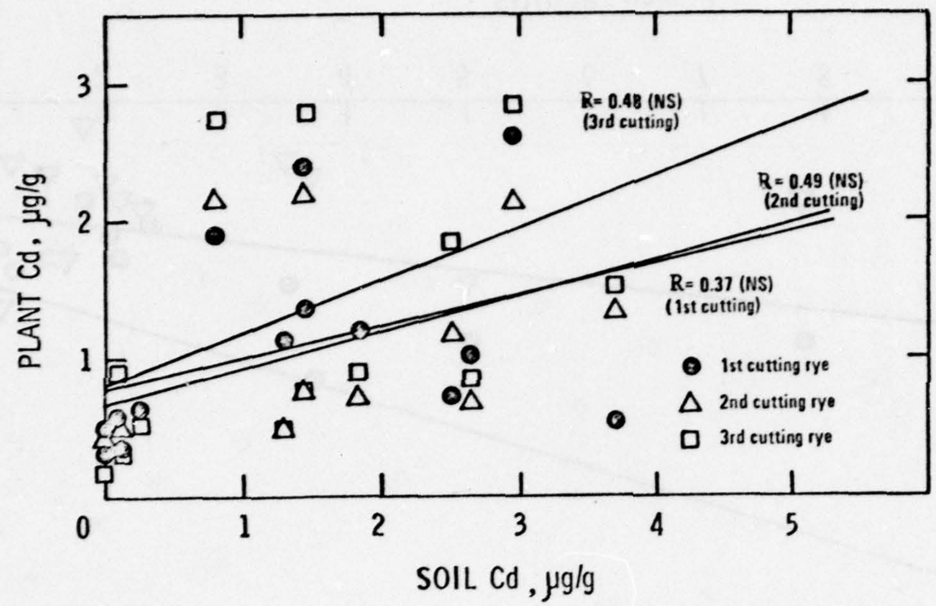


Figure 42. DTPA-extractable cadmium from soil versus concentration of cadmium in ryegrass

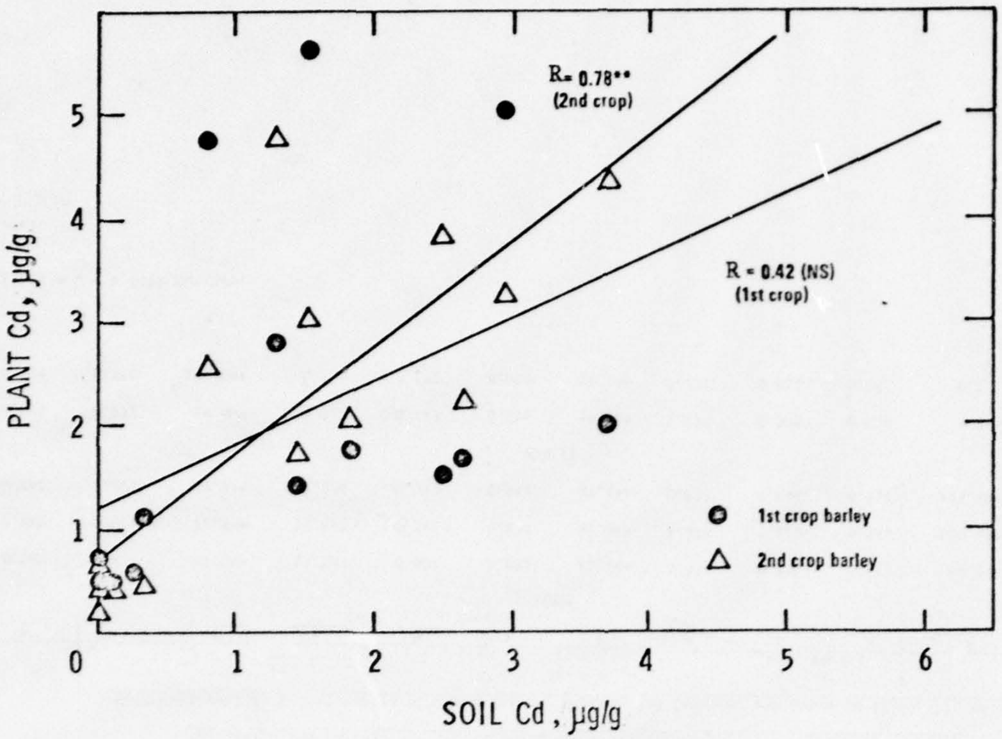


Figure 43. DTPA-extractable cadmium from soil versus concentration of cadmium in barley

Table 22

Regression and Correlation Coefficients and F-Statistics for Plant Uptake vs. Initial Soil Availability Relationships of Zinc, Copper, Nickel, and Cadmium, and Shown in Figures 36 through 43

| Cuttings/Crops | Zinc | | | | Copper | | | | Nickel | | | | Cadmium | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | a | b | R | F | a | b | R | F | a | b | R | F | a | b | R | F |
| **RYE** | | | | | | | | | | | | | | | | |
| 1st cutting | 67.648 | 0.868 | 0.821 | 27.0** | 13.598 | 0.301 | 0.872 | 41.4** | 0.954 | 0.746 | 0.883 | 46.2** | 0.754 | 0.225 | 0.372 | 2.0 |
| 2nd cutting | 41.335 | 0.941 | 0.921 | 72.5** | 15.690 | 0.361 | 0.871 | 41.0** | 1.309 | 0.610 | 0.945 | 109.4** | 0.660 | 0.261 | 0.491 | 4.1 |
| 3rd cutting | 49.694 | 0.762 | 0.805 | 23.9** | 17.934 | 0.319 | 0.860 | 37.1** | 0.837 | 0.844 | 0.951 | 123.4** | 0.801 | 0.381 | 0.480 | 2.9 |
| **BARLEY** | | | | | | | | | | | | | | | | |
| 1st crop | 55.103 | 0.634 | 0.771 | 19.0** | 8.767 | 0.163 | 0.776 | 19.7** | 1.220 | 0.305 | 0.234 | 0.8 | 1.225 | 0.604 | 0.417 | 2.7 |
| 2nd crop | 31.118 | 0.999 | 0.950 | 100.6** | 9.932 | 0.172 | 0.809 | 24.7** | 0.791 | 0.012 | 0.087 | 0.1 | 0.693 | 1.026 | 0.783 | 20.6* |

Regression equation Plant Nutrient = a + b Soil Nutrient.

** Significant at 95 percent level.

# PART VII: CONCLUSIONS

Dredged material behaves similar to productive Minnesota soils and can be beneficial for increasing crop production when mixed with marginal soils. The beneficial effects of adding dredged material to marginal soils are a) increased available water capacity, b) increased nutrient supply when fine-textured dredged material is mixed with coarse-textured marginal soils, and c) higher hydraulic conductivities which improve drainage when coarse-textured dredged material is mixed with fine-textured marginal soils. High organic matter content and the amorphous (non-crystalline) nature of the clay-size fraction of dredged material contribute to its high soil and water retention values.

The concentrations of zinc, copper, and nickel in dredged material can be used to predict the uptake of these elements in plants grown on dredged material. Large amounts of sulfur in the dredged material required large applications of lime to neutralize the acidity. Excessive soluble salts did not limi plant growth in this study. The oil and grease content of the dredged material was greater than for the marginal soils but did not limit plant growth.

The dredged material samples used in this study were selected because they were believed to be low in contaminants. The chemical analyses demonstrated that they did not contain excessive concentrations of contaminants to restrict growth or contaminate the harvested plant material.

In general, yield ratios were greater than two for crops grown on fine-textured dredged material when mixed with coarse-textured marginal soils. The yields on the pure dredged material were equal to or greater than the yields on the productive Minnesota soils.

## PART VIII: GUIDELINES FOR USE OF DREDGED MATERIAL ON AGRICULTURAL LAND

A highly attractive alternative for disposing of dredged sediments is to use these materials beneficially to amend marginal lands for agricultural purposes. By the addition of dredged material, the physical and chemical characteristics of a marginal soil can be altered to such an extent that water and nutrients become more available for the growth of higher plants. In some cases, raising the elevation of the soil surface with dredged material may improve surface drainage, reduce water tables, and reduce the frequency of flooding. When considering the feasibility of an agricultural use for dredged material, factors such as physical and chemical properties, weed control, land preparation, and farm operations must be appraised.

Most agricultural soils of economic importance are some type of loam (USDA classification) which possesses desirable quantities of sand, silt, and clay. Figure 44 presents a guide for the textural classification of soils. Textural classification helps to determine not only the nutrient-supplying ability of a soil material, but also the supply and exchange of water and air which is so important to plant life. Therefore, an important criterion should be to adjust the textural classification of the final mixture of dredged material and marginal soil to approximate a loam. Thus, mixing a fine-textured dredged material (high in proportions of clay and silt) with a coarse-textured marginal soil (high in sand content) to the proportions of a loam would improve its physical and chemical characteristics. An example calculation for obtaining a desirable loam texture follows:

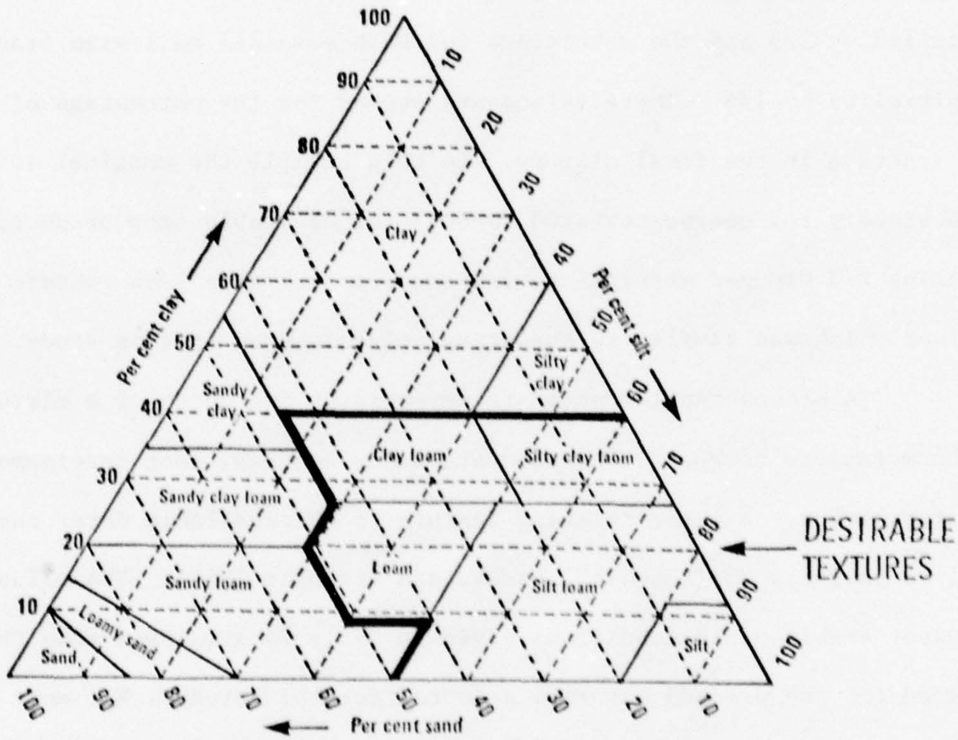


Figure 44. Guide for textural classification of soils (Soil Survey Staff, 1960)

| | Sand | Silt | Clay | Texture |
|---|---|---|---|---|
| | | percent | | |
| N.J. dredged material | 14.0 | 52.0 | 33.5 | Silty clay loam |
| Marginal soil | 91.0 | 5.0 | 4.1 | Sand |
| Mixture: 2/3 dredged material - 1/3 sand | 40.1 | 36.2 | 23.7 | Loam |
| Sandy mixture | 39.9 | 40.0 | 20.3 | Loam |

The percentage for each particle size fraction of dredged material is multiplied by 2/3 and the percentage for each marginal soil size fraction is multiplied by 1/3. These values are summed for the percentage of each size fraction in the final mixture. In this example the marginal soil was obviously too coarse-textured (sandy) for desirable crop production. By mixing 2/3 dredged material to 1/3 sand, a desirable loam texture was obtained which was similar to the actual mixture used in this study.

A second consideration in determining the depth of a mixture is those factors necessary for adequate water storage, root development, and crop yields. A guide relating texture to the available water capacity is given in Table 23 (Longwell, Parks, and Springer 1963). The values which represent stable yield conditions given in Table 24 are lower than those measured for the dredged material selected for this study. For most grain crops (corn, wheat, oats, etc.) a minimum of 7.5 cm of water storage in the top metre of soil (Table 24) is desirable. If the objective is to grow a satisfactory grass crop for soil cover without maximizing yields, then somewhat less than 7.5 cm/m of available water storage is required. The minimum water storage capacity of 7.5 cm/m of soil may be conditioned by the amount and frequency of rainfall or irrigation.

For the New Jersey example used above, the following available water-holding capacities from Table 23 would be expected:

Table 23

Available Water Capacity of Soils of Different Textural Classes in Tennessee (Longwell, Parks, and Springer 1963)

| Textural Class | Available Water Capacity[1/] cm of Water/cm of Soil Depth |
|---|---|
| Sand | 0.015 |
| Loamy sand | 0.074 |
| Sandy loam | 0.121 |
| Fine sandy loam | 0.171 |
| Very fine sandy loam | 0.257 |
| Loam | 0.191 |
| Silt loam | 0.234 |
| Silt | 0.256 |
| Sandy clay loam | 0.209 |
| Silty clay loam | 0.204 |
| Sandy clay | 0.085 |
| Silty clay | 0.180 |
| Clay | 0.156 |

1/ As estimated by the difference between the quantities of water held at matrix suctions of 0.34 and 15.2 bars.

Table 24

Desirable Available Water Capacity (AWC)[1/] Suitable for Agricultural Crops

| Available Water Capacity cm Water/cm Soil | Total Available Water Capacity Per Metre of Soil | Recommended Plants |
|---|---|---|
| $<0.05$ | $< 5.0$ | Not suitable for most agricultural crops unless irrigated. |
| 0.05-0.075 | 5.0-7.5 | Best suited for grasses. |
| $> 0.075$ | $> 7.5$ | Suitable for most agricultural crops. |

1/ Difference between 0.33 and 1 bar volumetric water contents.

| Depth m | Material | Texture | Available water-holding capacity in 1 metre of soil cm |
|---|---|---|---|
| 1 | N.J. dredged material | Silty clay loam | 20.4 |
| 1 | Soil | Sand | 1.5 |
| 1 | Mixture: 2/3 dredged material - 1/3 soil | Loam | 19.1 |
| .4 | Mixture (upper .4 m) | | 7.6) 8.5 |
| .6 | Soil (lower .6 m) | | 0.9) |

Based on this example, enough dredged material (0.66 x 0.4 m = 0.27 m would need to be applied such that the resulting mixture would be 0.4 m thick. The total available water-holding capacity of the 1-m depth would be 8.5 cm. In this example, the type of farm equipment required to incorporate and mix the dredged material has not been examined.

Nonfood crops, such as lawn sod and related horticultural products, and food crops, such as small grains, row crops, pastures, and orchards, are logical candidates for a productive use of dredged material. However, vegetation grown in saline, weed-infested, contaminated dredged material may lead to economic problems.

The question as to whether or not to produce food or nonfood crops often depends upon the chemical contaminants present in the dredged material. As dredging operations occasionally take place in harbors containing industrial wastes and sediment runoff from agricultural areas, this material may contain toxic levels of heavy metals, oil and grease, pesticides, and high nutrient concentrations of fertilizer. Chemical analysis of the dredged material should detect contaminants; however, an important consideration is the solubility of specific constituents whose concentrations are high since soluble forms are readily available to the biological food chain.

Suggested tolerance levels of zinc, copper, nickel, and cadmium (Melsted 1973) in Table 18 and plant uptake relationships in Figures 36 through 43 can be used to decide the ratio of dredged material and marginal soil in the final mixture. For example, from Figure 40 the concentration of nickel in plant tissue (9 µg/g) grown on New Jersey dredged material (10.94 µg/g) is above tolerance level (3 µg/g). Thus, to bring such concentration in plant tissue below tolerance level, concentration in the final mixture should not be more than 3 µg/g (Figure 40). Hence, the concentration of dredged material (X) in the final mixture can be calculated as follows:

$10.94\ X = 0.36\ (1 - X) = 3.0$, where concentration of nickel in New Jersey soil is 0.36 µg/g. Thus X = 0.25. Hence, the final mixture should be 1/4 dredged material and 3/4 marginal soil.

The chemical analysis of dredged material should provide data to determine the nutrient availability and to establish recommended fertilizer application for agricultural production. The chemical properties which require greatest attention other than heavy metals are the standard soil tests for nitrogen, phosphorus, potassium, sulfur, lime requirement, and soluble salts. If the dredged material is from a coastal or tidal region special attention must be given to high salinity (mainly sodium) contents as crop production may be difficult to establish.

A general guide for the application of agricultural limestone to medium-textured soils based on soil pH is given in Table 25. These recommendations should be only followed in the absence of data on buffer index. More exact recommendations can be obtained locally.

Table 25

General Recommendations for Liming Medium-Textured Acid Soils

| Soil pH | General Lime Recommendations to Bring Soil to pH 6.5 metric tons/ha |
|---|---|
| 3.0-4.0 | 20 |
| 4.0-5.0 | 18 |
| 5.0-5.5 | 15 |
| 5.5-6.0 | 10 |
| 6.0-6.5 | 5 |

Dredged material with low pH's but with large amounts of reduced sulfur will require larger amounts of lime than will other dredged material with the same pH. It is suggested that lime requirements be determined from incubation studies for dredged material containing high levels of sulfur.

Recommended rates of fertilizer can be taken from Table 26 or for more specific recommendations from the State Soil Testing Service or County Agricultural Extension Service.

Crop selection for food use is dependent upon desires of the land owner, physical and chemical problems of the soil, and economic considerations. Nonfood crops, related to nursery and horticultural products, are regionally dependent and because of marketing problems are usually located near metropoliatan centers. The type of vegetative production desired should in part be based on the soil texture, drainage conditions, and soluble salt concentrations of the soil mixture.

Vegetation is difficult to establish in areas of high salinity (Table 1). Occasionally salt water can become mixed with dredged material and limit vegetation to plant species which are salt tolerant. Salt tolerant vegetative species are usually not economically productive. However, the use of weed-free, non-saline dredged material as a soil amendment to upgrade marginal soil is highly recommended.

In general, the uptake of minimal amounts of heavy metals in grain plants makes them a good crop if large amounts of heavy metals are present in dredged material mixed with soils. The heavy metals may concentrate in the leaves, however, making specific grain crops less desirable for harvesting for forage or silage.

Table 26

Phosphorus and Potassium Fertilizer Recommendations

| Relative Level | Phosphorus Soil Test kg/ha | Approximate Amount of $P_2O_5$ Needed Annually* kg/ha | Potassium Soil Test kg/ha | Approximate Amount of $K_2O$ Needed Annually* kg/ha |
|---|---|---|---|---|
| Low | 0-11 | 70 | 0-110 | 200 |
| Medium | 12-22 | 50 | 111-220 | 130 |
| High | 23-34 | 30 | 221-330 | 65 |
| Very High | over 34 | 0 | over 330 | 0 |

* Will vary with crop and location conditions.

## PART IX: FUTURE RESEARCH NEEDS

The present study was successful in detailing the chemical and physical properties of dredged material and in demonstrating the potential for improving marginal soils with dredged material. However, some areas need further research and demonstration. They are:

a. Field studies are needed to validate the greenhouse plant growth responses. Because of the wide differences in environment between the greenhouse and field, plant response could be quantitatively different.

b. Additional crops such as corn, wheat, and soybeans need to be tested in the field. Barley and ryegrass were used as experimental crops in this study because of their suitability to greenhouse environments.

c. A more detailed analysis of the clay fraction of dredged material is needed. Preliminary results in this study suggest that the clay fraction in a number of dredged material samples is amorphous. This may explain the high water-holding capacities and low bulk densities of the materials.

d. The development of a lime requirement method to determine the amount of lime necessary to overcome sulfide oxidation in dredged material.

e. Additional research is needed to determine heavy metal availability to plants and to define what are excessive amounts of heavy metals in dredged material.

f. What are the tolerance levels of heavy metals for plant growth and human consumption?

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# APPENDIX A: PHYSICAL CHARACTERISTICS

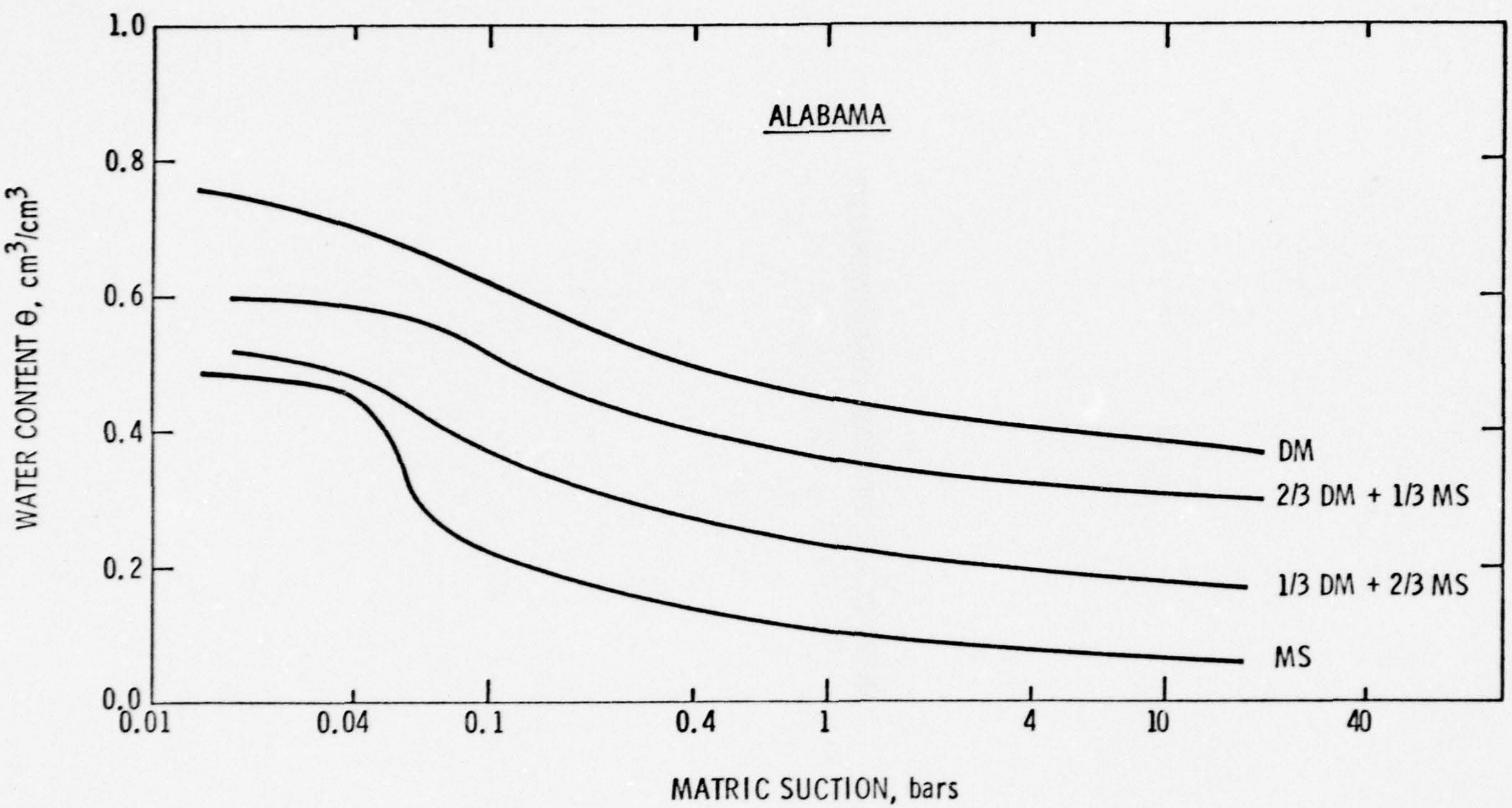


Figure A1. Water retention characteristics of dredged material, marginal soil and their mixtures from Alabama

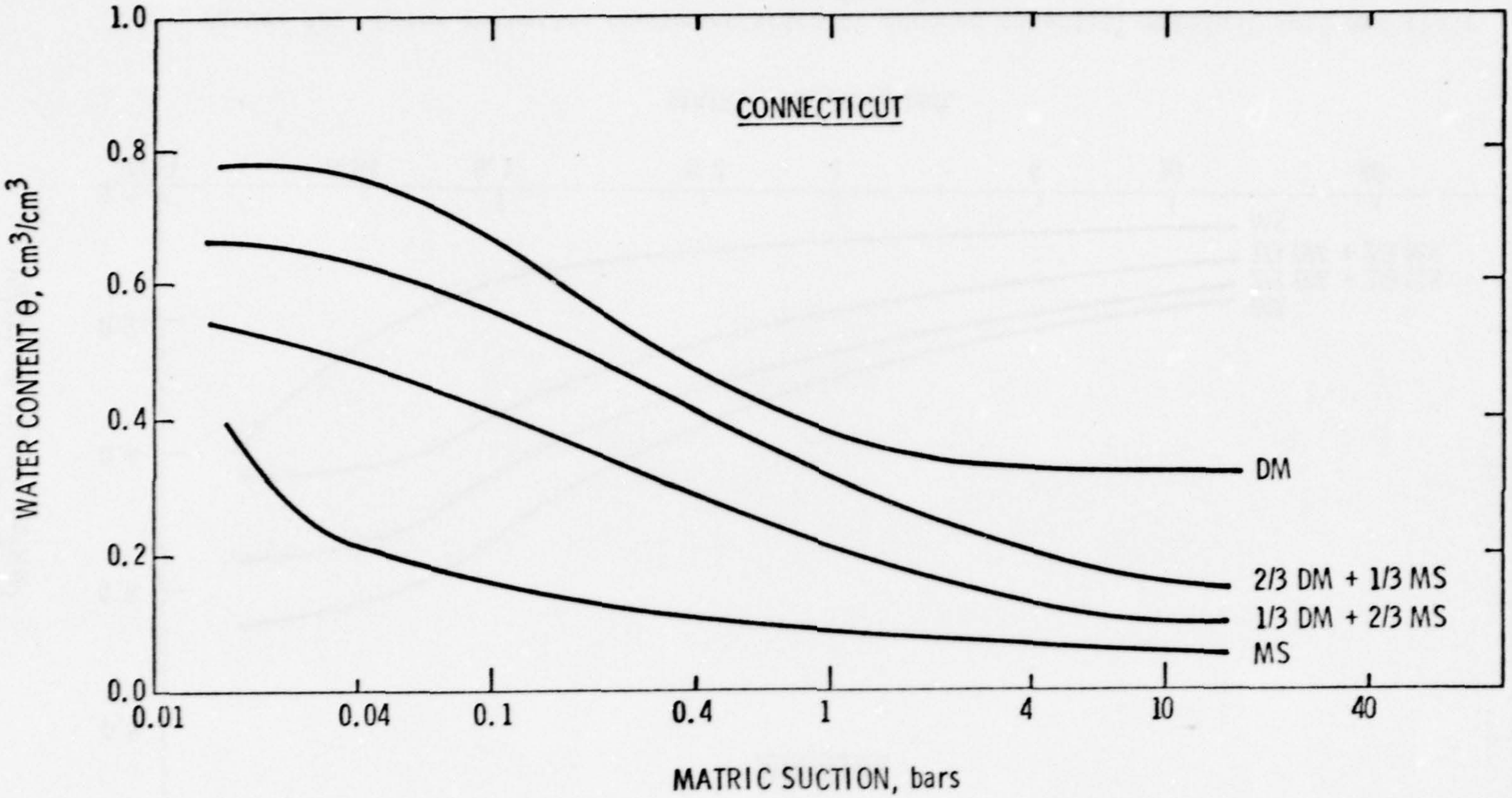


Figure A2. Water retention characteristics of dredged material, marginal soil and their mixtures from Connecticut

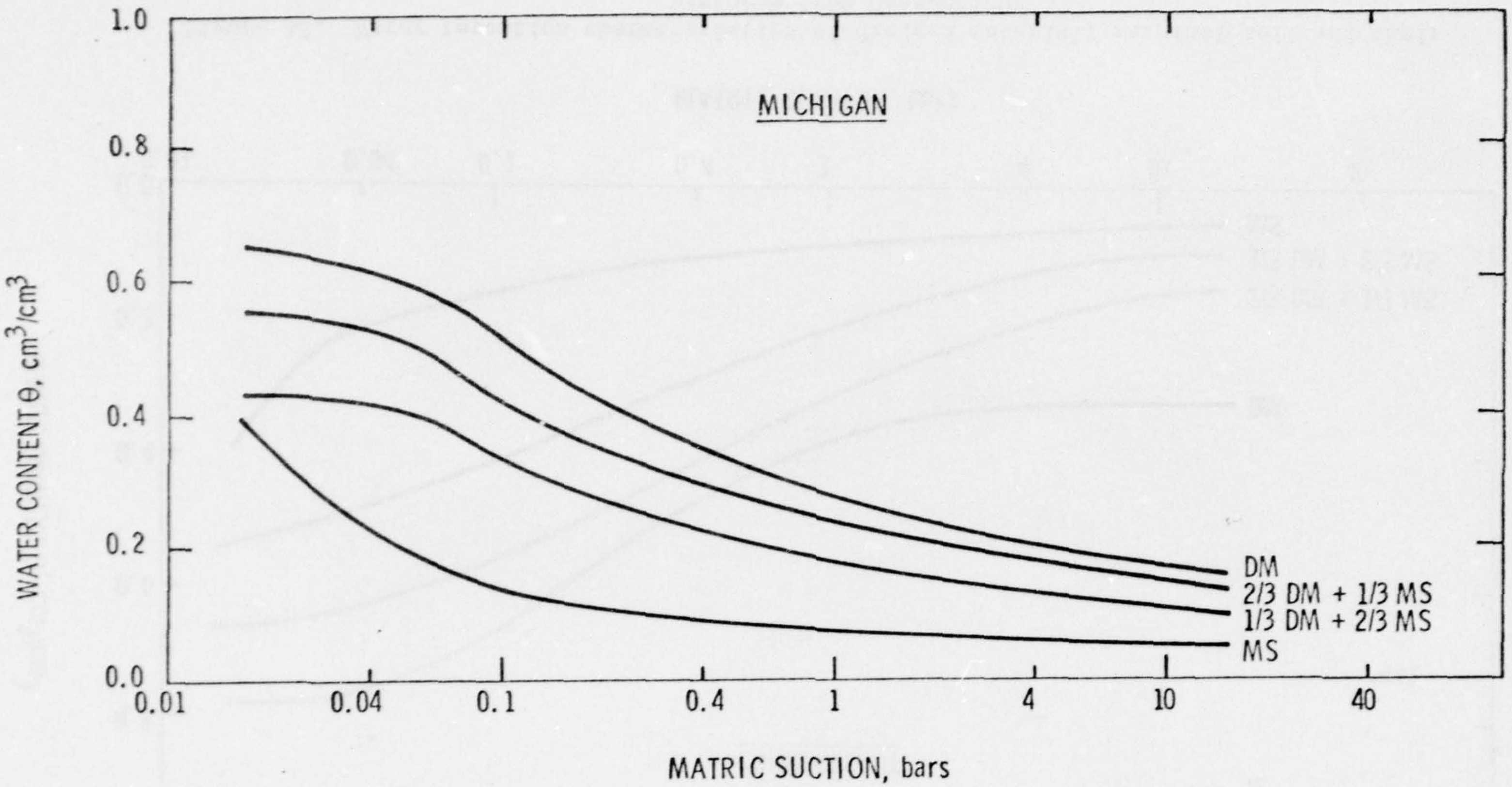


Figure A3. Water retention characteristics of dredged material, marginal soil and their mixtures from Michigan

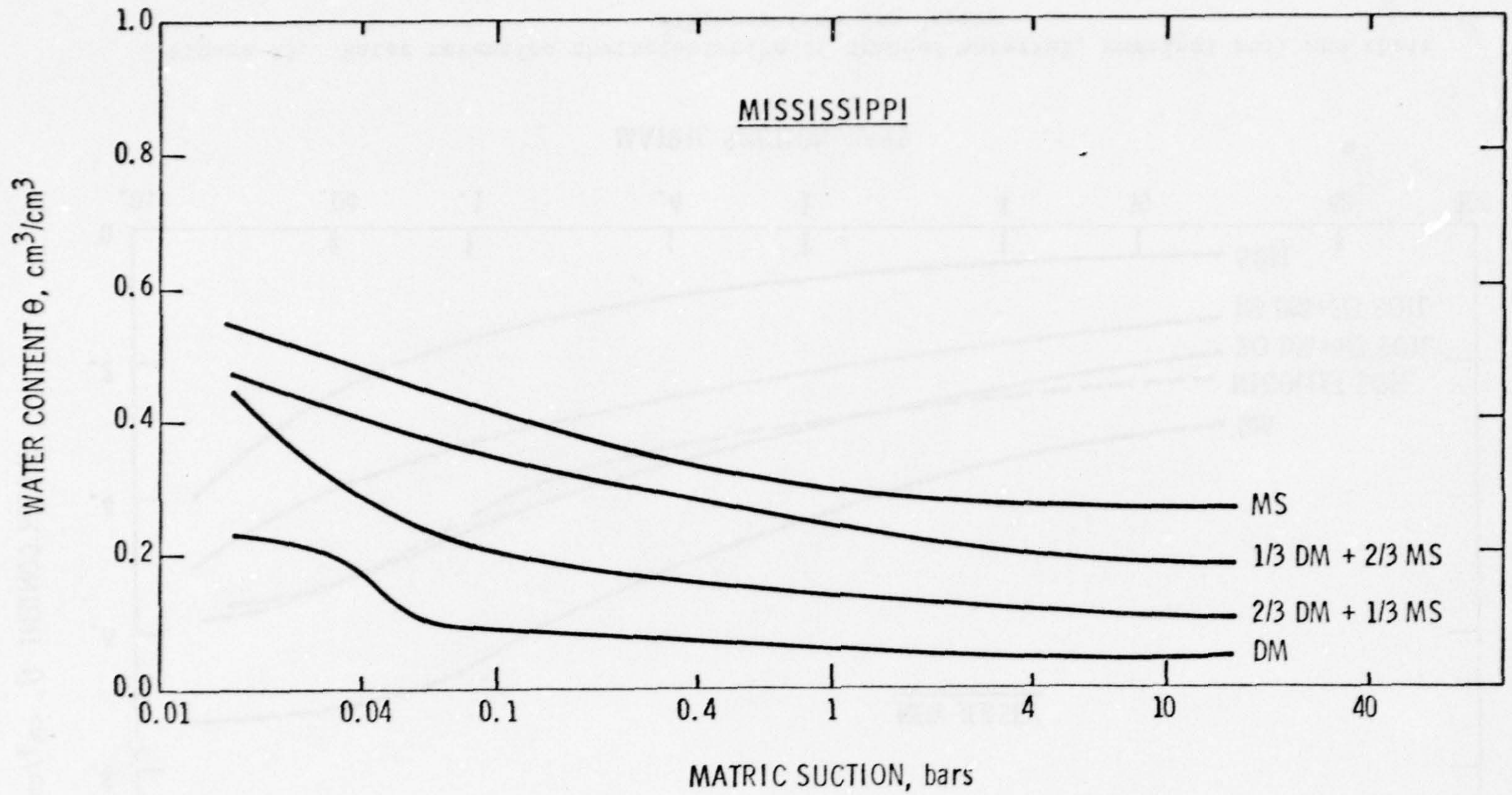


Figure A4. Water retention characteristics of dredged material, marginal soil and their mixtures from Mississippi

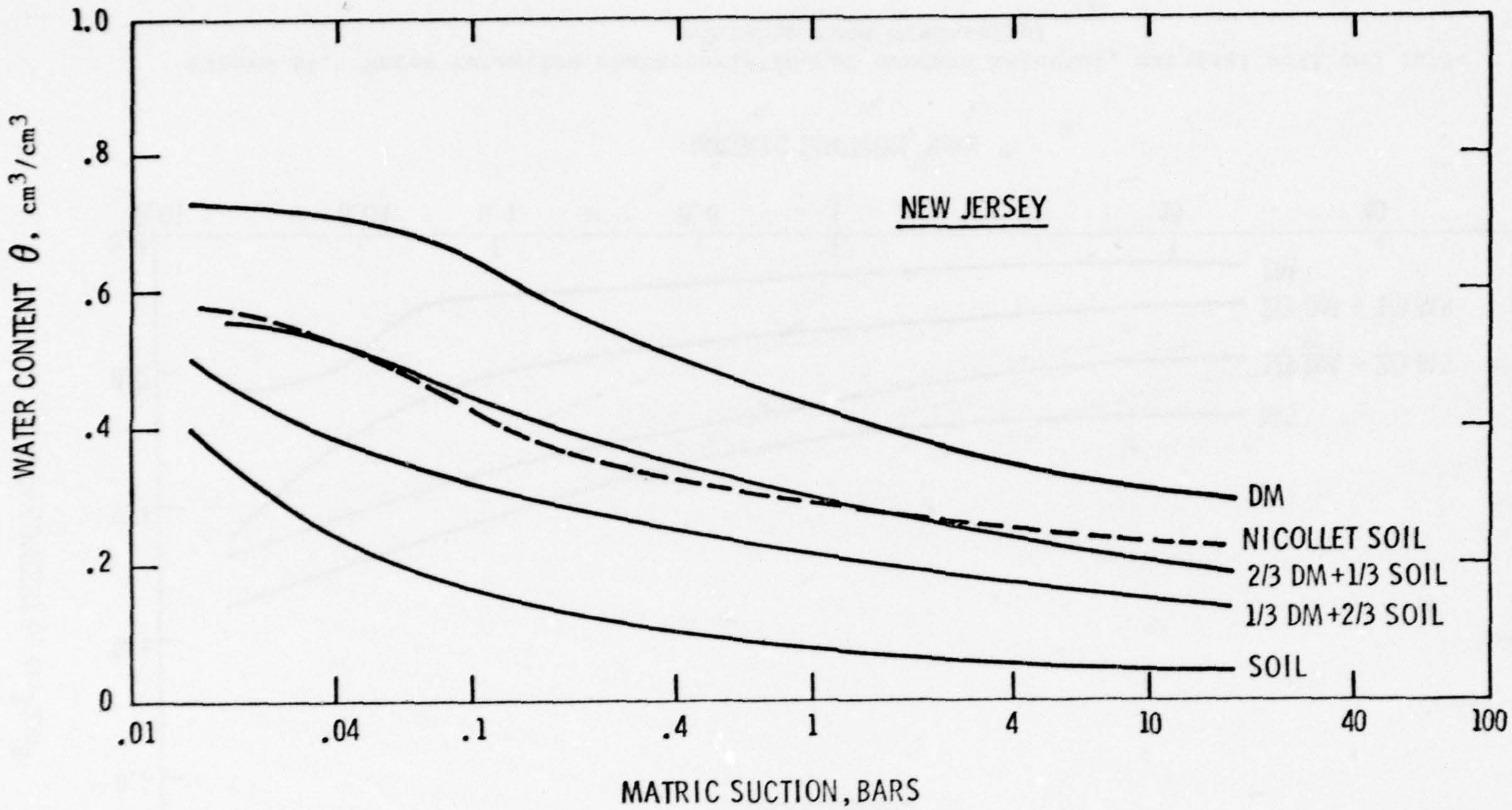


Figure A5. Water retention characteristics of dredged material, marginal soil and their mixtures from New Jersey

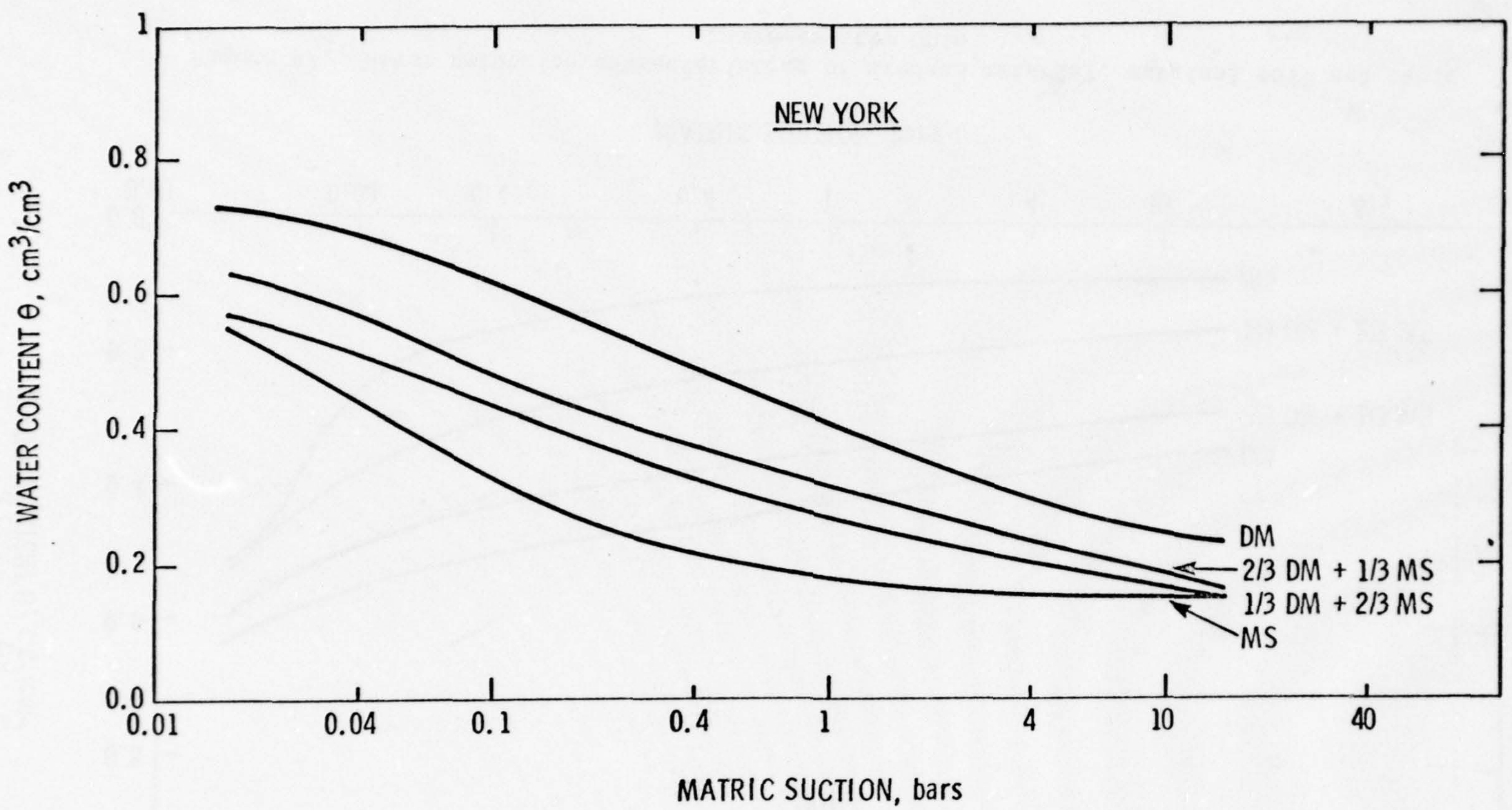


Figure A6. Water retention characteristics of dredged material, marginal soil and their mixtures from New York

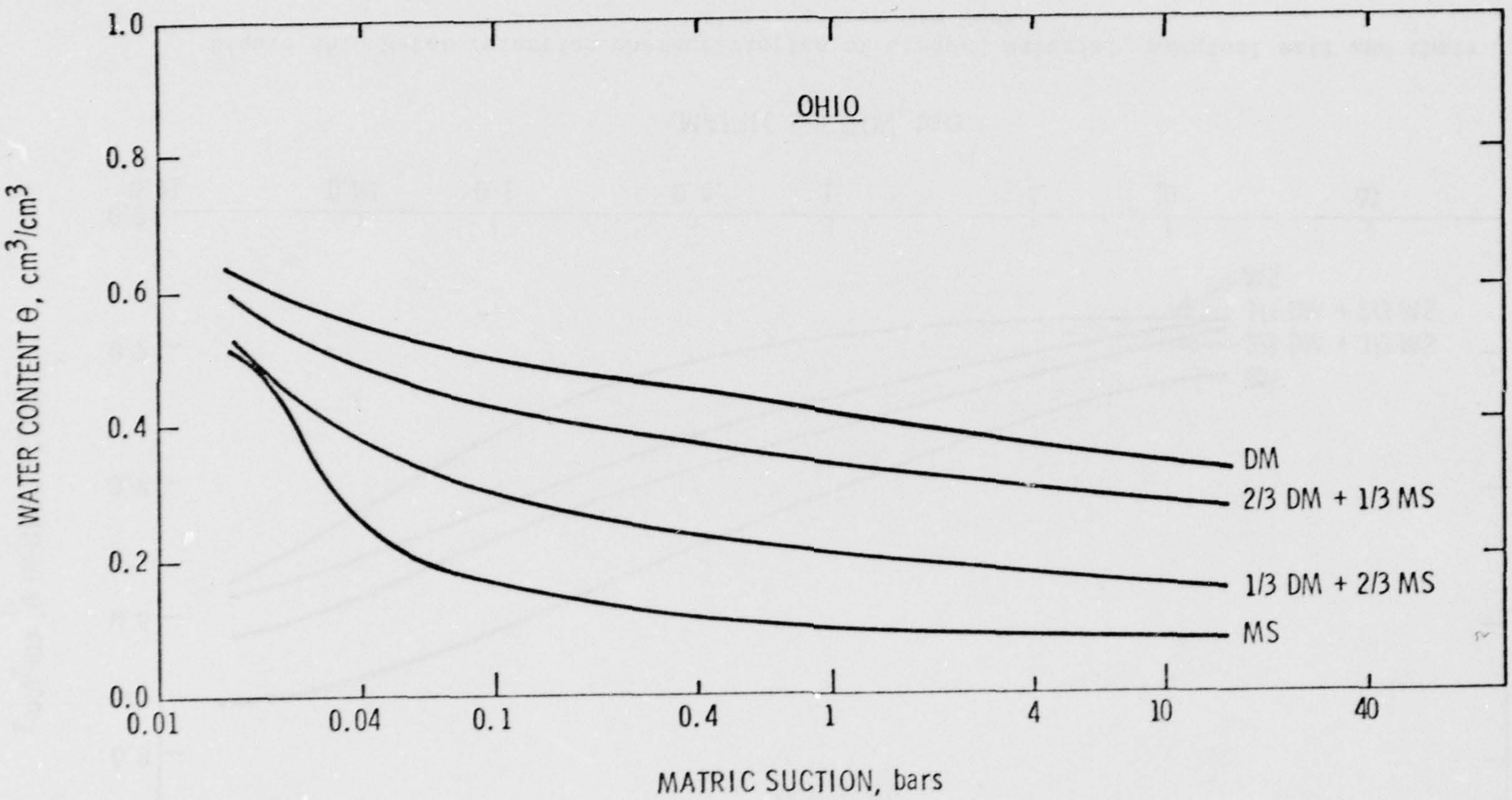


Figure A7. Water retention characteristics of dredged material, marginal soil and their mixtures from Ohio

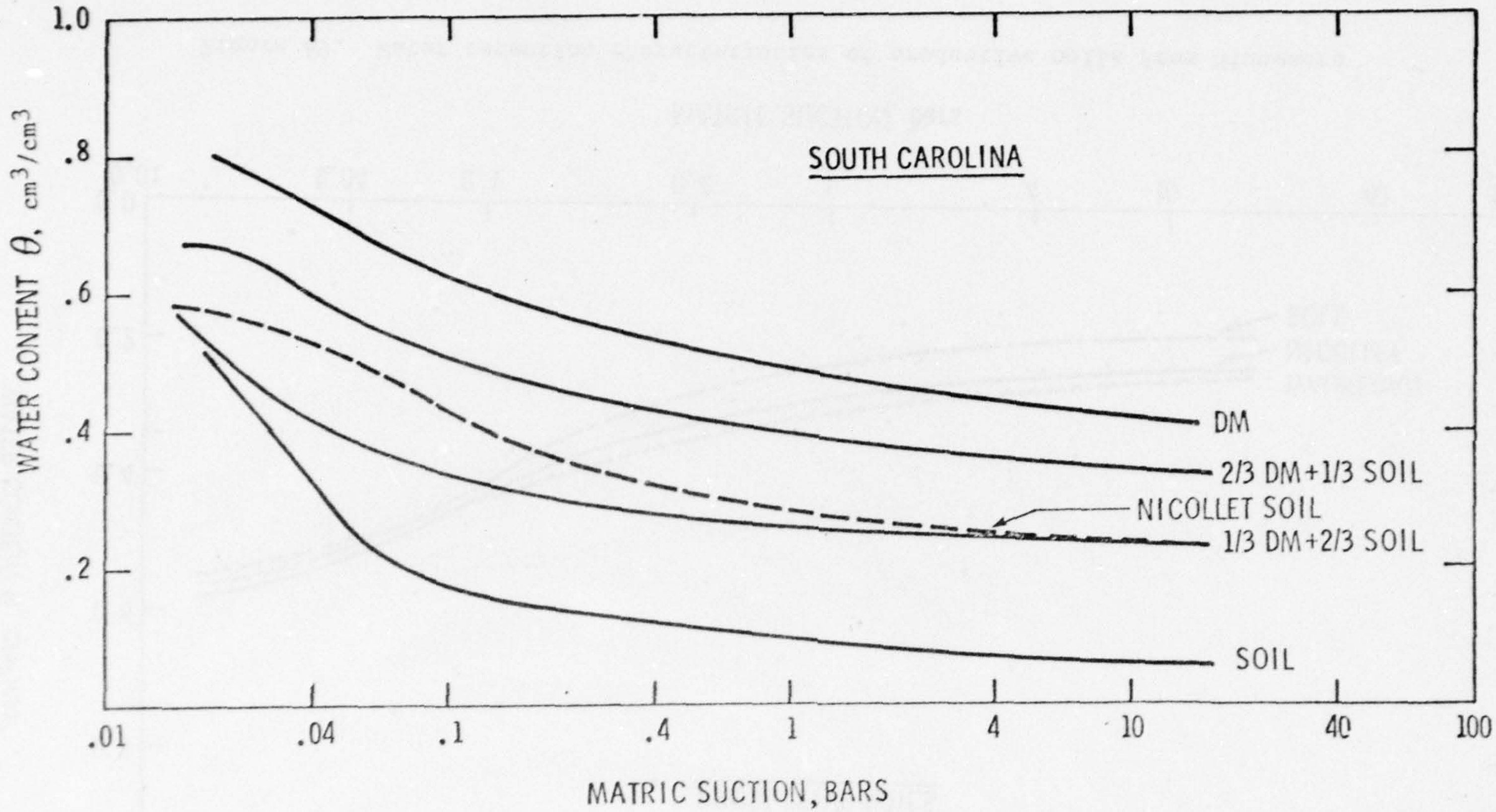


Figure A8. Water retention characteristics of dredged material, marginal soil and their mixtures from South Carolina

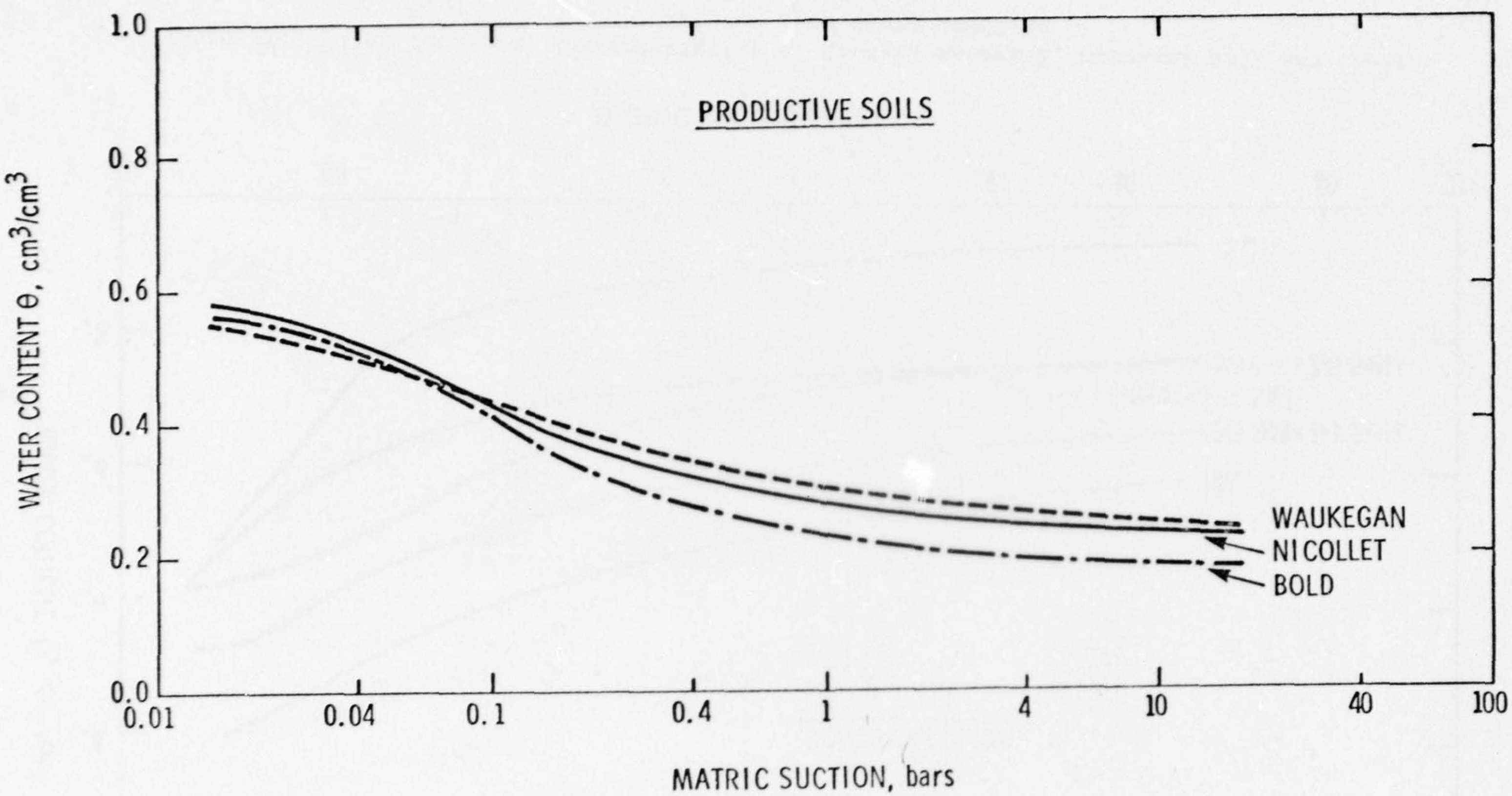


Figure A9. Water retention characteristics of productive soils from Minnesota

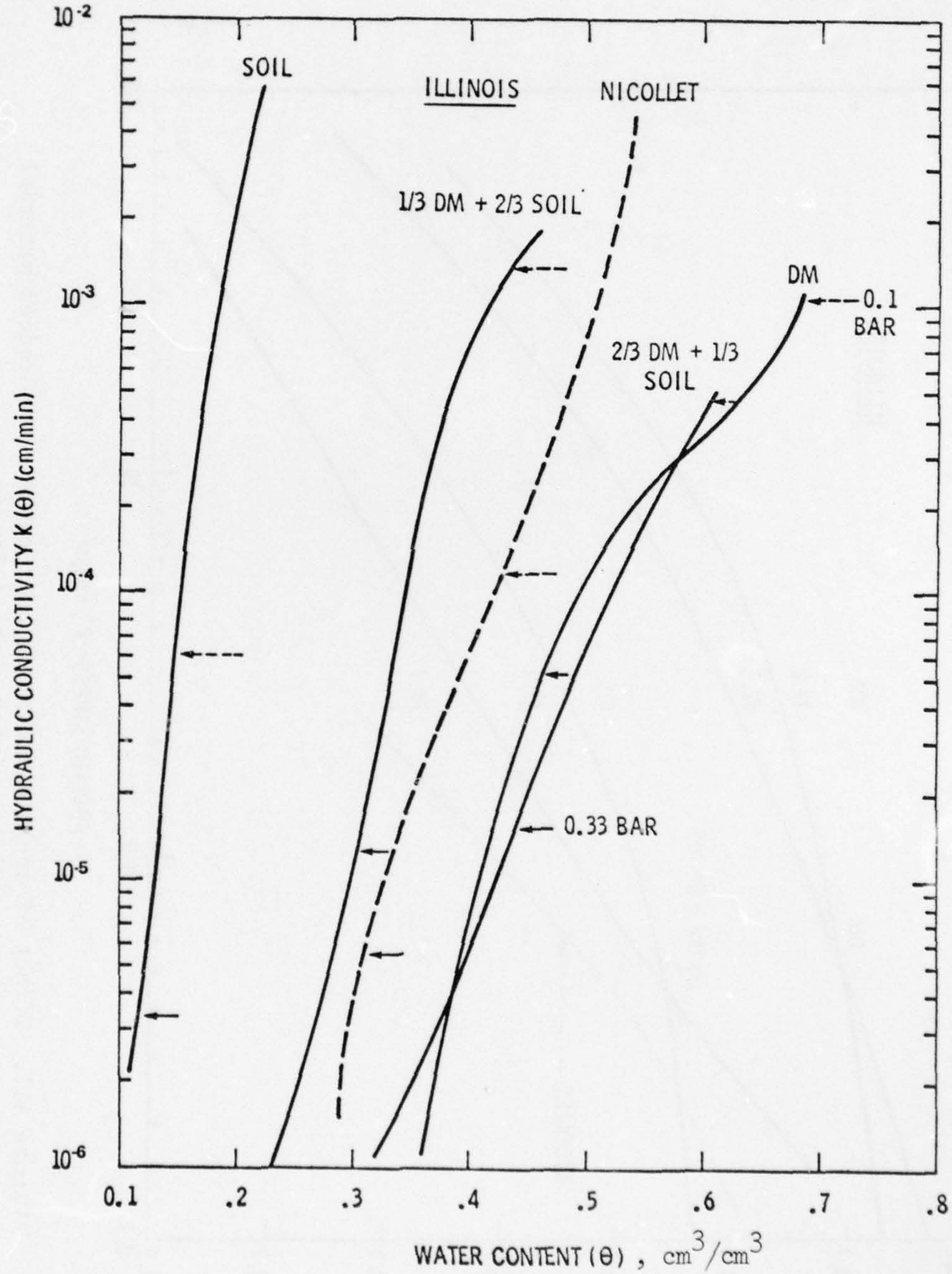


Figure A10. Unsaturated hydraulic conductivity versus water content for Illinois treatments and for Nicollet soil

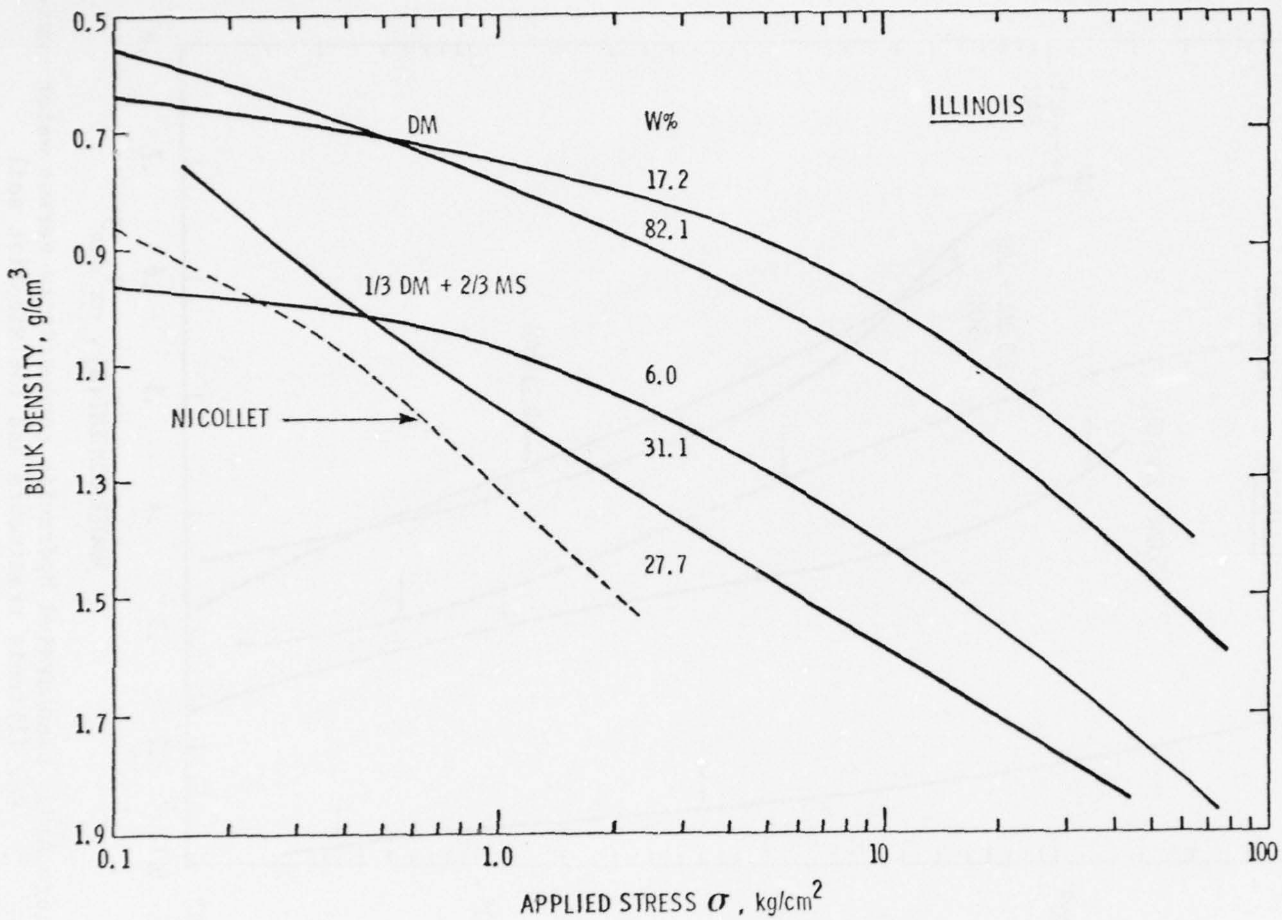


Figure A11. Effect of applied stress on bulk density of dredged material and its mixture from Illinois

# APPENDIX B: CLAY MINERAL ANALYSES

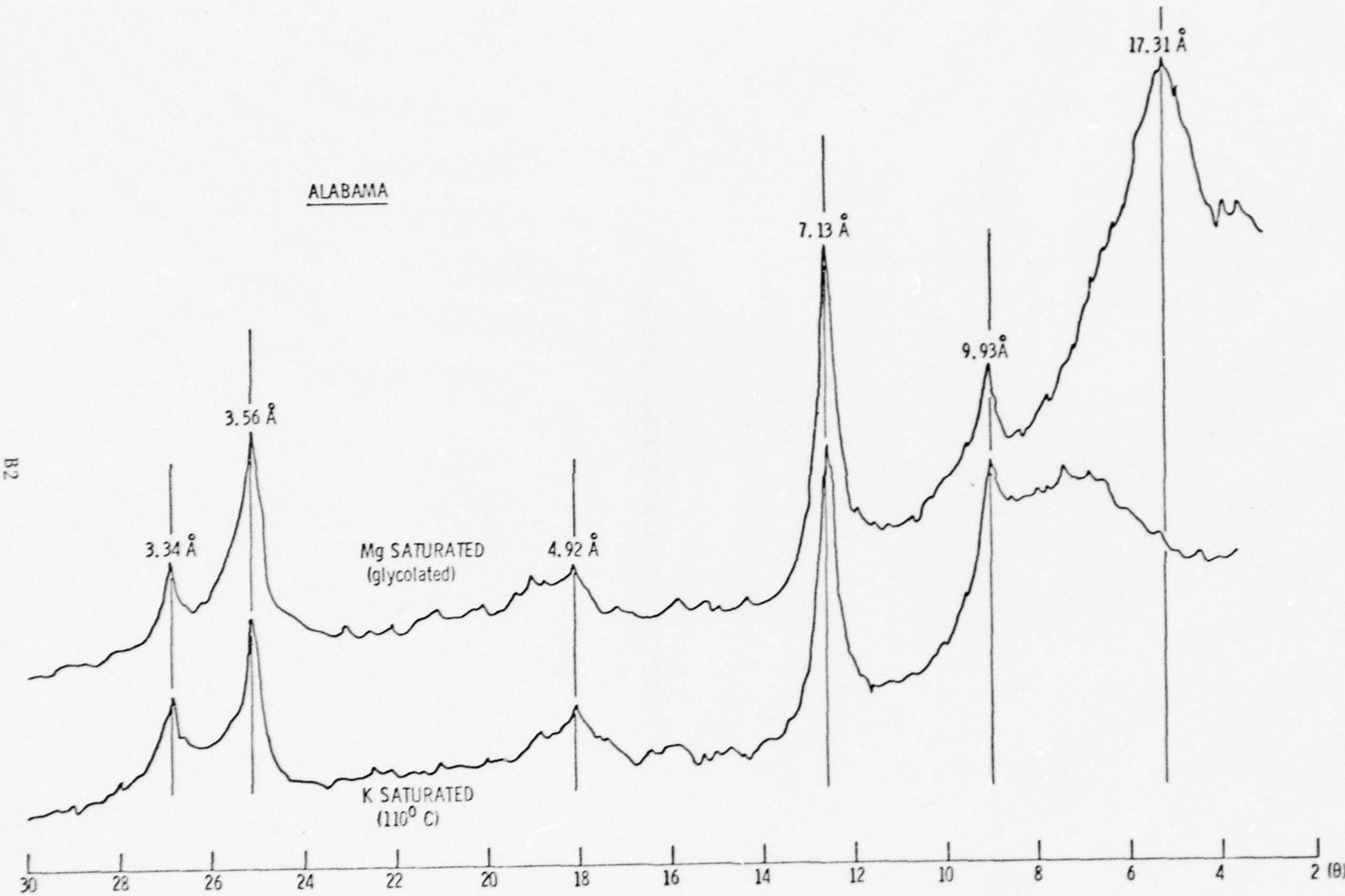


Figure B1. X-ray diffractogram of Alabama dredged material

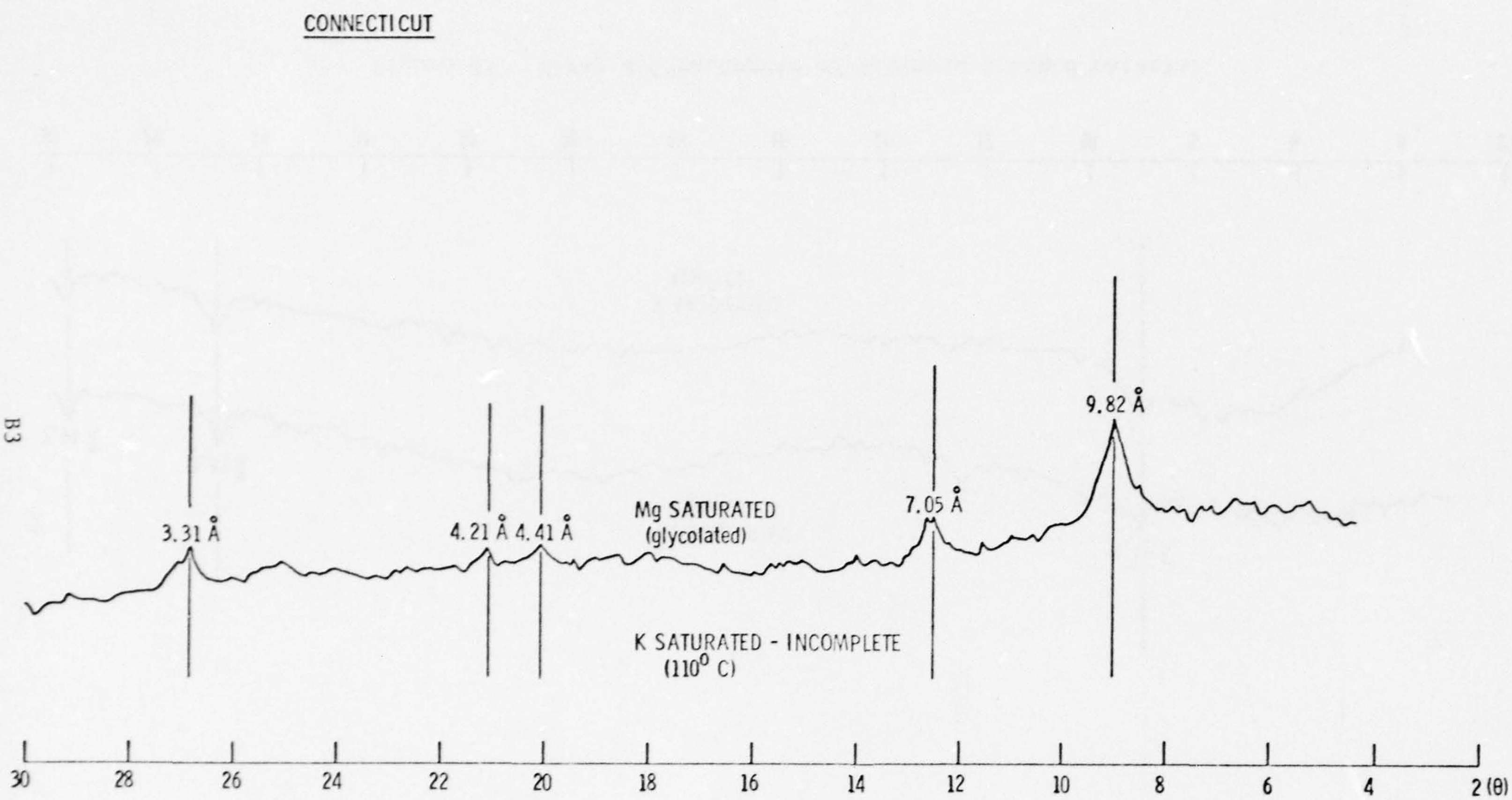


Figure B2. X-ray diffractogram of Connecticut dredged material

ILLINOIS

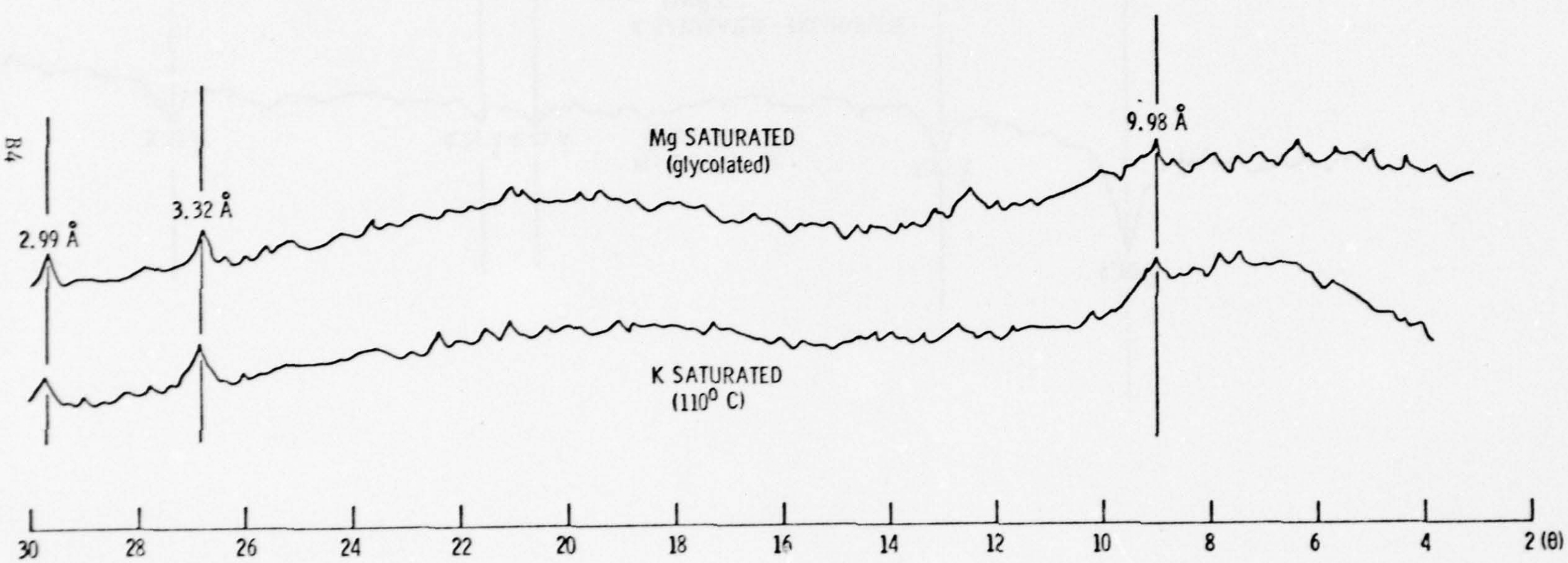


Figure B3. X-ray diffractogram of Illinois dredged material

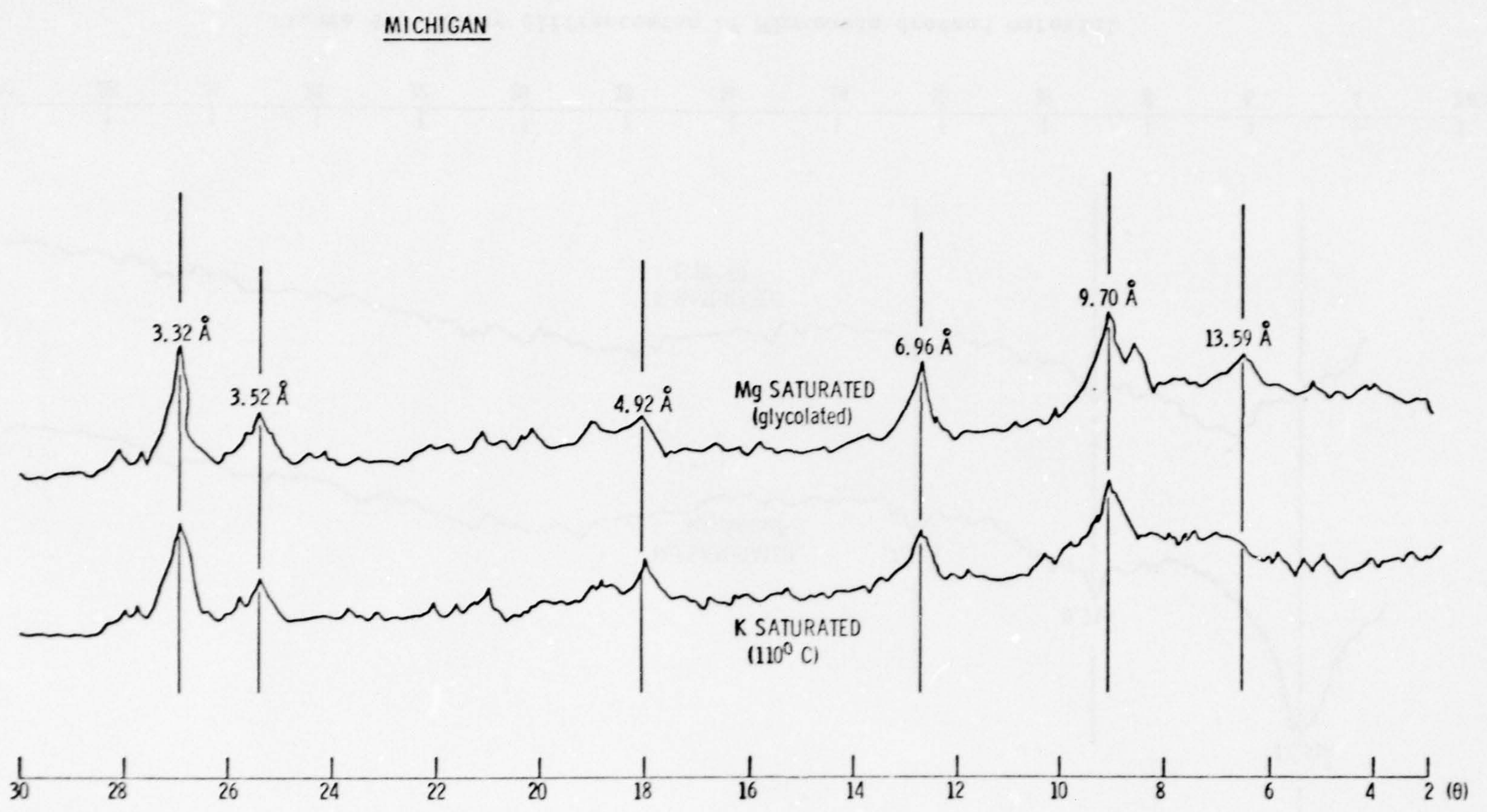


Figure B4. X-ray diffractogram of Michigan dredged material

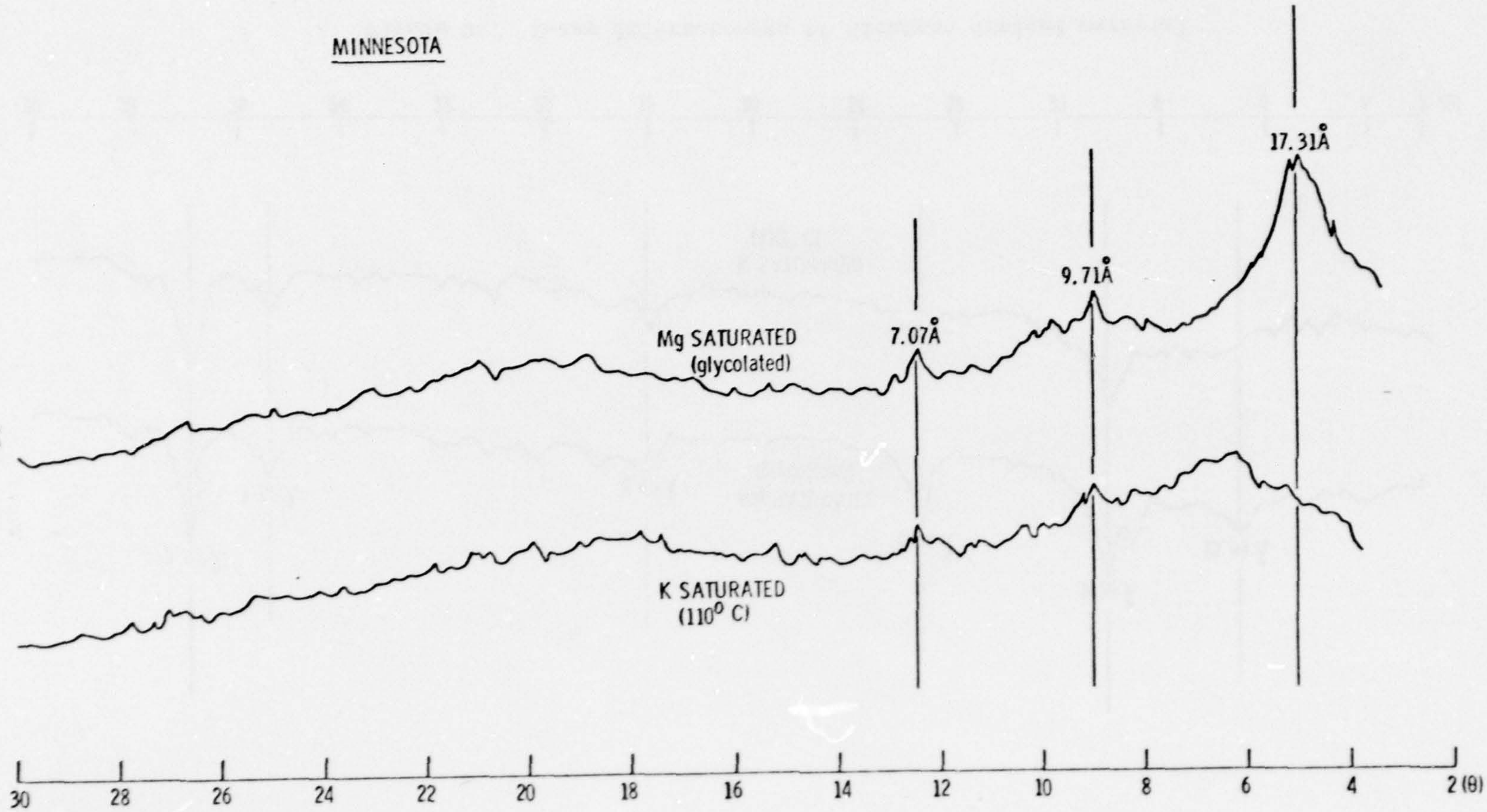


Figure B5. X-ray diffractogram of Minnesota dredged material

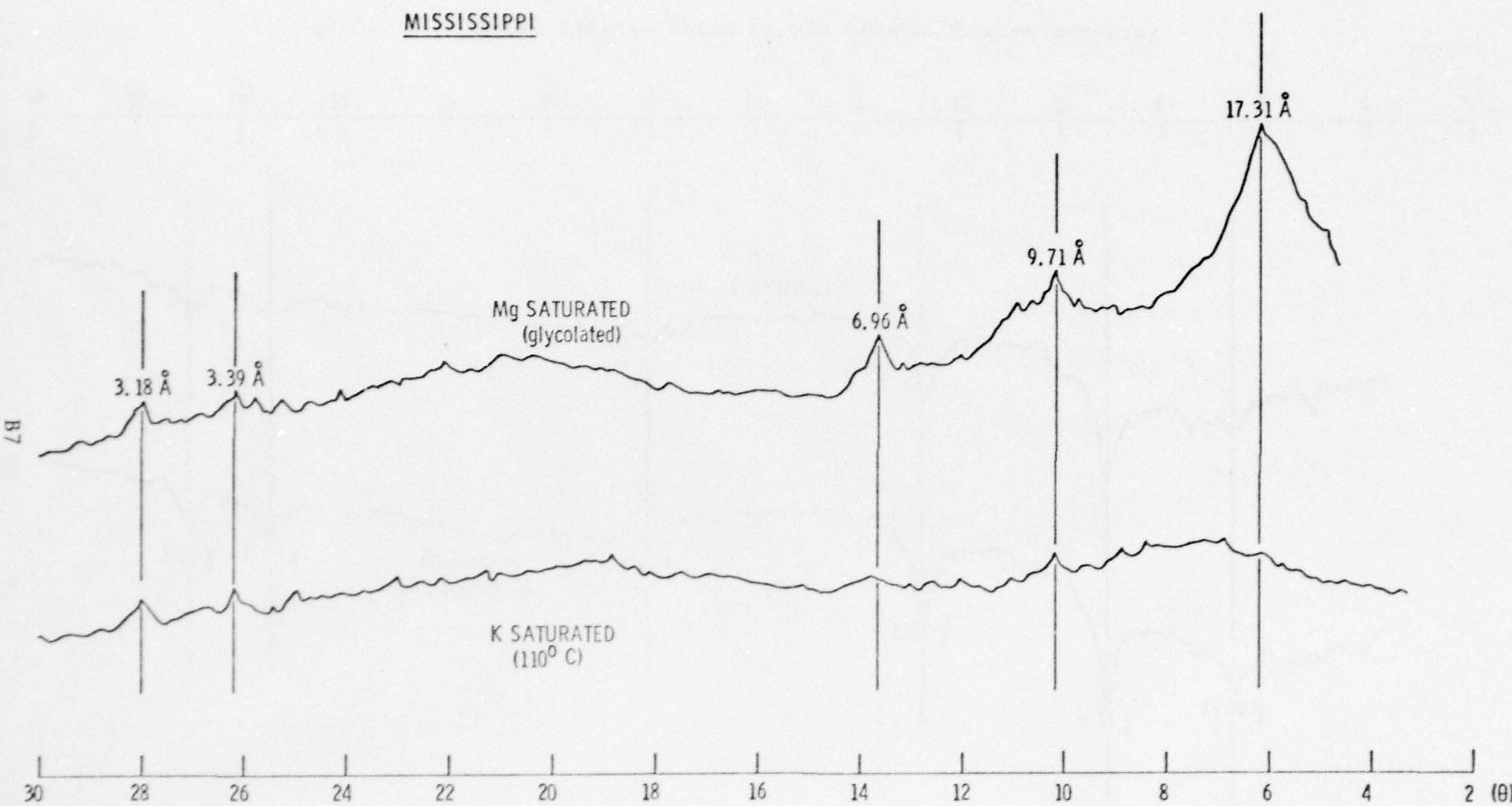


Figure B6. X-ray diffractogram of Mississippi dredged material

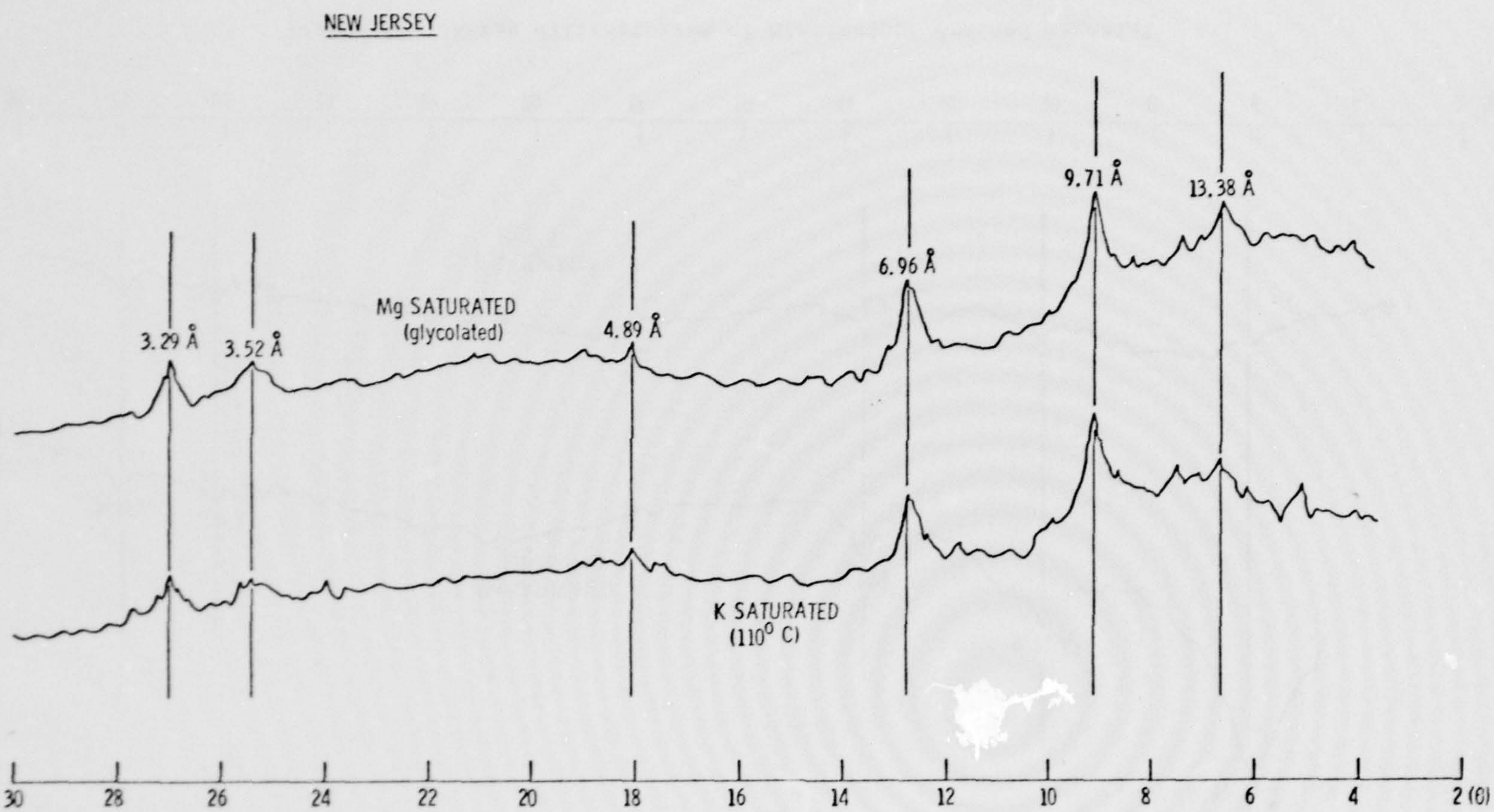


Figure B7. X-ray diffractogram of New Jersey dredged material

NEW YORK

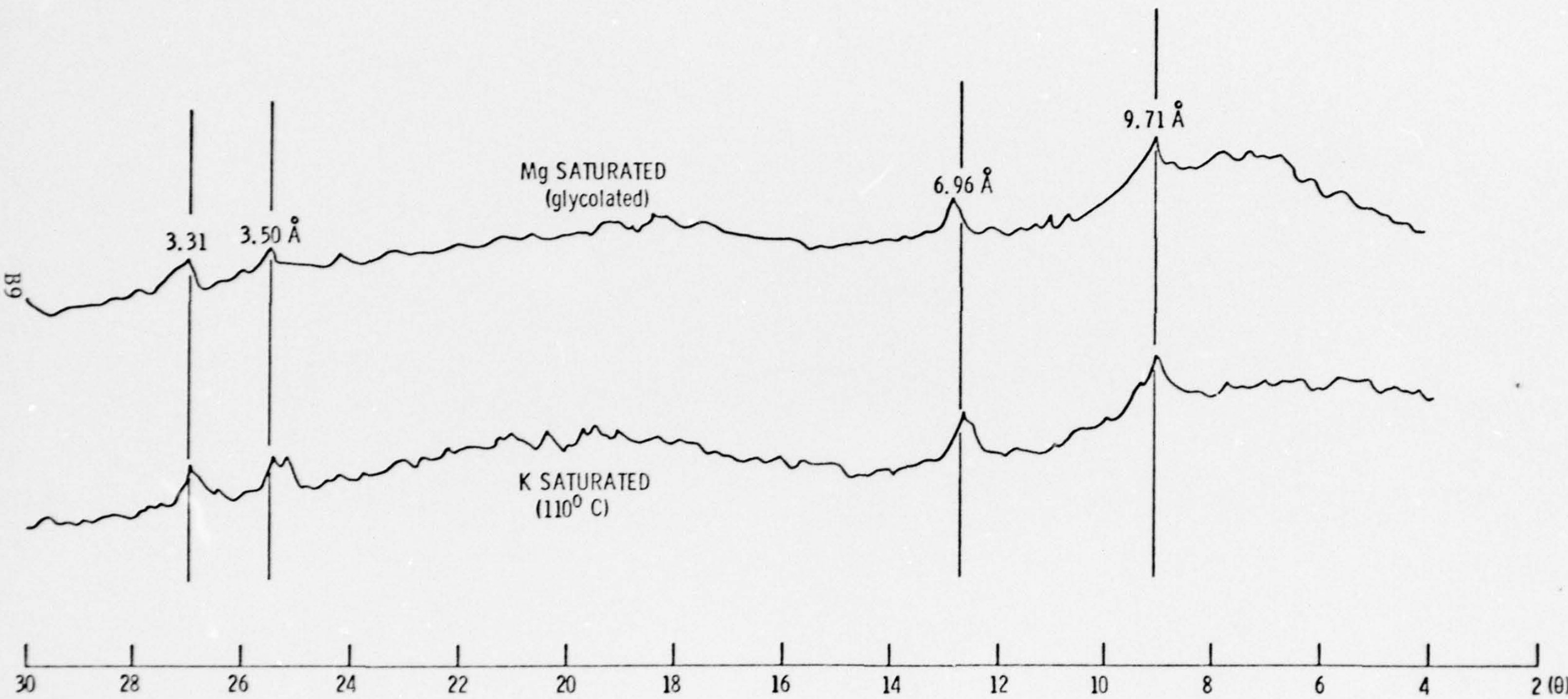


Figure B8. X-ray diffractogram of New York dredged material

# APPENDIX C: ELEMENTAL ANALYSES OF PLANTS

Table C1

Elemental Analysis of First Cutting Ryegrass.* Values Expressed as μg/g.

| | P | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ala DM | 2055 | 66293 | 4541 | 4368 | 53 | 142 | 10331 | 234 | 206.2 | 26.0 | 133.3 | 6.2 | 4.62 | 2.22 | 0.52 |
| Ala 2/3 DM | 1784 | 54380 | 7102 | 6374 | 62 | 163 | 9200 | 226 | 172.7 | 25.6 | 143.3 | 10.7 | 3.52 | 4.02 | 0.87 |
| Ala 1/3 DM | 1898 | 54568 | 6137 | 6551 | 192 | 218 | 12207 | 299 | 127.2 | 24.5 | 80.8 | 6.7 | 2.35 | 2.38 | 0.73 |
| Ala Soil | 952 | 37409 | 11928 | 6585 | 95 | 127 | 623 | 145 | 46.5 | 15.3 | 13.2 | 9.4 | 4.42 | 0.69 | 0.26 |
| Conn DM | 3424 | 51255 | 3614 | 5278 | 129 | 777 | 2750 | 60 | 56.2 | 17.2 | 19.9 | 32.3 | 2.13 | 1.25 | 0.38 |
| Conn 2/3 DM | 5756 | 41499 | 6527 | 5647 | 182 | 690 | 6457 | 130 | 69.7 | 24.1 | 15.7 | 26.2 | 1.46 | 1.37 | 0.64 |
| Conn 1/3 DM | 4689 | 46808 | 5999 | 5645 | 121 | 413 | 3102 | 180 | 71.4 | 24.9 | 17.9 | 22.6 | 1.82 | 1.26 | 0.56 |
| Conn Soil | 3593 | 30334 | 11283 | 9687 | 167 | 258 | 1968 | 42 | 49.5 | 17.9 | 13.2 | 11.5 | 1.76 | 1.00 | 0.50 |
| Ill DM | 2667 | 27497 | 13370 | 4746 | 92 | 187 | 14123 | 97 | 81.1 | 22.2 | 28.4 | 3.5 | 2.18 | 0.68 | 0.19 |
| Ill 2/3 DM | 2242 | 31308 | 13289 | 4817 | 34 | 134 | 13895 | 105 | 87.2 | 16.1 | 22.5 | 2.7 | 1.49 | 0.71 | 0.21 |
| Ill 1/3 DM | 2020 | 34732 | 12768 | 4571 | 34 | 127 | 9399 | 84 | 65.1 | 13.5 | 17.2 | 2.0 | 1.21 | 0.74 | 0.54 |
| Ill Soil | 2569 | 50243 | 14355 | 5363 | 42 | 123 | 1627 | 71 | 60.9 | 15.8 | 15.0 | 3.2 | 1.89 | 0.75 | 0.31 |
| Mich DM | 6416 | 27948 | 10493 | 4314 | 32 | 140 | 12843 | 217 | 164.0 | 32.4 | 35.1 | 3.0 | 8.95 | 0.00 | 1.02 |
| Mich 2/3 DM | 6226 | 28769 | 10880 | 4870 | 35 | 155 | 9280 | 273 | 157.3 | 30.2 | 38.2 | 5.3 | 8.65 | 0.02 | 1.18 |
| Mich 1/3 DM | 6792 | 33010 | 12032 | 5068 | 40 | 154 | 6168 | 234 | 120.1 | 25.0 | 28.2 | 7.3 | 6.42 | 0.96 | 1.37 |
| Mich Soil | 6195 | 40133 | 8215 | 6143 | 85 | 148 | 462 | 44 | 64.7 | 15.9 | 16.0 | 4.8 | 2.12 | 0.05 | 0.59 |

*Values are averages of analysis of five replicate treatment pots.

Table C1 (continued)

| | P | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Minn DM | 1879 | 38261 | 23965 | 4069 | 11 | 119 | 2931 | 230 | 65.1 | 18.5 | 20.3 | 2.7 | 3.03 | 0.55 | 1.22 |
| Minn 2/3 DM | 3162 | 42266 | 15699 | 4924 | 40 | 131 | 4867 | 44 | 41.7 | 11.9 | 13.6 | 3.5 | 2.32 | 0.73 | 0.65 |
| Minn 1/3 DM | 2277 | 50644 | 14654 | 4223 | 65 | 151 | 5038 | 40 | 38.1 | 11.3 | 15.8 | 3.7 | 2.03 | 0.84 | 0.46 |
| Minn Soil | 2339 | 57686 | 12608 | 3804 | 42 | 130 | 3655 | 48 | 37.3 | 11.3 | 14.7 | 3.7 | 1.99 | 0.79 | 0.39 |
| Miss DM | 828 | 41397 | 18478 | 3802 | 44 | 113 | 859 | 215 | 43.6 | 12.5 | 26.5 | 6.2 | 4.47 | 4.09 | 0.12 |
| Miss 2/3 DM | 2762 | 54783 | 14342 | 3421 | 93 | 155 | 3195 | 63 | 38.9 | 16.4 | 13.9 | 2.9 | 2.74 | 0.80 | 0.20 |
| Miss 1/3 DM | 3163 | 60932 | 14624 | 3934 | 56 | 134 | 2650 | 45 | 39.2 | 15.6 | 13.1 | 3.4 | 2.67 | 0.71 | 0.34 |
| Miss Soil | 2761 | 60893 | 12642 | 3607 | 50 | 134 | 2352 | 50 | 41.6 | 15.0 | 15.0 | 3.2 | 3.32 | 6.65 | 0.44 |
| NJ DM | 4295 | 58465 | 7140 | 5304 | 100 | 342 | 1174 | 134 | 173.9 | 20.6 | 31.8 | 26.2 | 5.15 | 1.11 | 0.94 |
| NJ 2/3 DM | 4106 | 51448 | 8526 | 6146 | 97 | 313 | 1481 | 134 | 222.3 | 20.0 | 29.3 | 31.4 | 13.61 | 1.14 | 1.05 |
| NJ 1/3 DM | 4743 | 48469 | 7837 | 6567 | 201 | 466 | 1912 | 270 | 119.5 | 21.5 | 21.4 | 30.8 | 4.14 | 1.40 | 0.71 |
| NJ Soil | 5183 | 21356 | 7838 | 7875 | 222 | 438 | 1833 | 159 | 38.6 | 19.1 | 23.1 | 22.6 | 1.75 | 1.40 | 0.40 |
| NY DM | 1892 | 53465 | 14722 | 2651 | 32 | 116 | 3259 | 184 | 152.4 | 38.0 | 38.3 | 1.6 | 2.28 | 0.72 | 0.52 |
| NY 2/3 DM | 2261 | 50399 | 16323 | 2466 | 37 | 137 | 5323 | 174 | 137.9 | 40.4 | 25.7 | 3.8 | 1.86 | 0.90 | 0.72 |
| NY 1/3 DM | 3668 | 50808 | 14526 | 2795 | 25 | 142 | 2265 | 225 | 157.9 | 34.7 | 20.0 | 5.0 | 2.05 | 0.20 | 1.14 |
| NY Soil | 1584 | 32919 | 10013 | 7097 | 22 | 104 | 205 | 138 | 69.3 | 12.2 | 19.7 | 3.5 | 1.81 | 0.00 | 0.64 |

Table C1 (concluded)

| | P | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ohio DM | 6143 | 46426 | 8481 | 3419 | 33 | 147 | 4651 | 89 | 87.8 | 17.5 | 21.7 | 6.5 | 2.17 | 0.00 | 2.60 |
| Ohio 2/3 DM | 5114 | 39843 | 8600 | 3631 | 32 | 147 | 5245 | 98 | 87.9 | 17.5 | 21.8 | 5.7 | 2.28 | 0.00 | 2.39 |
| Ohio 1/3 DM | 4551 | 35849 | 11236 | 4119 | 42 | 156 | 5478 | 115 | 79.8 | 19.6 | 21.6 | 4.1 | 2.33 | 1.23 | 1.89 |
| Ohio Soil | 2126 | 35816 | 8845 | 7630 | 38 | 122 | 856 | 70 | 73.8 | 9.0 | 19.2 | 4.1 | 1.10 | 0.00 | 0.50 |
| SC DM | 2200 | 64804 | 6264 | 3993 | 72 | 143 | 8106 | 192 | 85.0 | 17.4 | 99.8 | 4.5 | 1.42 | 0.87 | 0.25 |
| SC 2/3 DM | 1807 | 70810 | 7497 | 4205 | 47 | 139 | 7049 | 220 | 88.7 | 18.6 | 86.1 | 4.6 | 1.83 | 1.07 | 0.30 |
| SC 1/3 DM | 1522 | 61467 | 7186 | 4658 | 50 | 142 | 6121 | 181 | 83.7 | 16.4 | 77.9 | 4.4 | 1.44 | 1.15 | 0.36 |
| SC Soil | 753 | 30851 | 11579 | 6120 | 35 | 102 | 807 | 88 | 35.8 | 5.9 | 18.9 | 1.5 | 1.64 | 2.87 | 0.23 |
| Wauk- | 2049 | 55051 | 13718 | 4064 | 51 | 128 | 2608 | 73 | 31.6 | 9.4 | 17.5 | 4.1 | 1.88 | 0.94 | 0.33 |
| Port B. | 1698 | 63879 | 15225 | 4034 | 27 | 119 | 801 | 150 | 42.4 | 11.4 | 15.8 | 4.3 | 1.84 | 1.19 | 0.36 |
| Nicol. | 1523 | 60284 | 15812 | 4116 | 17 | 102 | 1260 | 58 | 46.2 | 10.3 | 16.3 | 3.5 | 2.5 | 0.72 | 0.64 |

Table C2

Elemental Analysis of Selected Second Cutting Ryegrass.* Values Expressed as µg/g.

| | P | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mich DM | 2994 | 13136 | 21967 | 5370 | 28 | 114 | 10682 | 224 | 85.0 | 34.8 | 27.6 | 2.3 | 8.43 | 0.69 | 0.68 |
| Mich 2/3 DM | 2571 | 14258 | 22976 | 4778 | 29 | 116 | 7685 | 256 | 73.2 | 33.4 | 34.0 | 2.2 | 6.37 | 0.65 | 0.73 |
| Mich 1/3 DM | 2837 | 17635 | 24846 | 4991 | 25 | 118 | 4396 | 241 | 59.6 | 29.4 | 30.7 | 4.0 | 4.19 | 0.72 | 0.77 |
| Mich Soil | 3512 | 26832 | 17099 | 7203 | 73 | 106 | 937 | 70 | 62.5 | 16.0 | 20.4 | 3.5 | 1.36 | 0.62 | 0.45 |
| NY DM | 1428 | 50449 | 21376 | 3571 | 34 | 119 | 4862 | 347 | 193.8 | 41.3 | 47.5 | 5.2 | 3.70 | 0.87 | 1.33 |
| NY 2/3 DM | 1884 | 36782 | 23798 | 3865 | 33 | 126 | 5848 | 326 | 152.0 | 45.2 | 37.1 | 5.2 | 3.19 | 0.87 | 1.17 |
| NY 1/3 DM | 1635 | 37058 | 25047 | 3969 | 39 | 135 | 3789 | 329 | 104.8 | 35.6 | 14.5 | 4.6 | 2.21 | 0.84 | 1.03 |
| NY Soil | 1306 | 29683 | 13597 | 7486 | 71 | 120 | 2000 | 81 | 40.0 | 14.5 | 19.2 | 2.2 | 1.98 | 0.51 | 0.46 |
| Ohio DM | 2942 | 39670 | 16253 | 4109 | 43 | 124 | 7583 | 59 | 63.4 | 19.2 | 23.0 | 2.8 | 2.99 | 0.60 | 2.13 |
| Ohio 2/3 DM | 2635 | 26992 | 19840 | 4317 | 33 | 121 | 5731 | 63 | 57.4 | 19.6 | 30.0 | 2.8 | 2.05 | 0.64 | 2.20 |
| Ohio 1/3 DM | 2260 | 19611 | 24292 | 5012 | 32 | 120 | 3333 | 87 | 52.6 | 19.0 | 33.3 | 2.9 | 1.72 | 0.64 | 2.14 |
| Ohio Soil | 1003 | 21483 | 15300 | 7653 | 35 | 95 | 1671 | 93 | 49.4 | 9.4 | 28.6 | 2.6 | 0.86 | 0.47 | 0.44 |
| Wauk. | 3070 | 29086 | 17760 | 6086 | 75 | 135 | 2383 | 97 | 37.7 | 9.5 | 29.1 | 4.5 | 2.52 | 0.79 | 0.46 |
| Port 6 | 1914 | 39174 | 18279 | 6224 | 51 | 134 | 2001 | 92 | 37.7 | 14.5 | 25.6 | 4.9 | 2.65 | 0.86 | 0.48 |
| Nicol. | 1506 | 33763 | 17800 | 6324 | 48 | 132 | 6077 | 67 | 47.6 | 19.6 | 24.9 | 4.6 | 3.05 | 0.73 | 0.57 |

* Values are averages of the analysis of 5 replicate treatment pots.

Table C3

Elemental Analysis of Selected Third Cutting Ryegrass,* Values Expressed as µg/g.

| | P | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mich DM | 2818 | 11030 | 34771 | 6905 | 29 | 99 | 4675 | 312 | 95.2 | 39.5 | 34.5 | 2.9 | 10.7 | 0.78 | 0.85 |
| Mich 2/3 DM | 2586 | 11713 | 33774 | 6521 | 17 | 111 | 3915 | 356 | 85.0 | 37.1 | 33.3 | 3.8 | 8.25 | 0.84 | 0.91 |
| Mich 1/3 DM | 2471 | 11803 | 33111 | 5846 | 16 | 105 | 2015 | 277 | 60.9 | 32.8 | 34.7 | 3.4 | 4.60 | 0.81 | 0.78 |
| Mich Soil | 4046 | 31215 | 21721 | 9859 | 19 | 63 | 851 | 194 | 119.4 | 18.2 | 23.6 | 4.3 | 2.61 | 0.79 | 0.92 |
| NY DM | 1575 | 42090 | 24257 | 4018 | 8 | 94 | 5010 | 504 | 158.9 | 39.6 | 25.8 | 3.4 | 2.79 | 0.67 | 1.52 |
| NY 2/3 DM | 1996 | 32022 | 33323 | 5088 | 20 | 101 | 4646 | 454 | 137.0 | 51.6 | 22.0 | 3.3 | 1.67 | 0.66 | 1.84 |
| NY 1/3 DM | 2087 | 30491 | 29156 | 5716 | 12 | 116 | 2335 | 560 | 128.0 | 35.0 | 24.5 | 9.6 | 2.59 | 0.74 | 2.29 |
| NY Soil | 1371 | 20770 | 20056 | 8475 | 11 | 89 | 2498 | 102 | 43.1 | 18.9 | 24.7 | 0.2 | 1.13 | 0.33 | 0.50 |
| Ohio DM | 3328 | 35630 | 22016 | 5252 | 7 | 102 | 3381 | 55 | 59.0 | 20.5 | 28.9 | 1.5 | 2.74 | 0.56 | 2.83 |
| Ohio 2/3 DM | 2720 | 26029 | 28214 | 5837 | 12.7 | 103 | 2143 | 54 | 54.5 | 20.9 | 30.4 | 3.4 | 2.46 | 0.64 | 2.81 |
| Ohio 1/3 DM | 2273 | 22785 | 35614 | 6208 | 34 | 94 | 1672 | 72 | 48.4 | 20.4 | 22.0 | 2.9 | 1.70 | 0.54 | 2.75 |
| Ohio Soil | 1117 | 16123 | 25655 | 9983 | 11 | 86 | 2095 | 173 | 47.7 | 11.8 | 29.7 | 0.5 | 0.63 | 0.42 | 0.52 |
| Wauk | 3033 | 21125 | 18501 | 6654 | 7 | 72 | 1577 | 104 | 34.2 | 12.3 | 18.2 | 2.3 | 2.50 | 0.50 | 0.20 |
| Port B | 2721 | 27794 | 23557 | 8613 | 11 | 95 | 1645 | 104 | 37.5 | 19.0 | 21.9 | 3.0 | 3.02 | 1.03 | 0.33 |
| Nicol | 1721 | 24491 | 22897 | 7947 | 7 | 92 | 2890 | 81 | 38.9 | 18.5 | 21.1 | 2.8 | 3.70 | 0.69 | 0.55 |

*Values are averages of analysis of 5 replicate treatment pots.

Table C4

Elemental Analysis of First Crop Barley.* Values Expressed as µg/g.

| | P | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ala DM | 1657 | 60055 | 5572 | 5680 | 64 | 124 | 23627 | 273 | 188.6 | 14.7 | 151.6 | 3.6 | 1.82 | 1.77 | 0.70 |
| Ala 2/3 DM | 1379 | 58566 | 7262 | 7119 | 102 | 150 | 21806 | 215 | 183.1 | 14.8 | 102.2 | 6.9 | 2.14 | 2.02 | 1.54 |
| Ala 1/3 DM | 1335 | 51801 | 7425 | 7877 | 89 | 140 | 27490 | 367 | 117.8 | 14.3 | 70.5 | 3.4 | 1.49 | 1.98 | 0.63 |
| Ala Soil | 464 | 17431 | 5992 | 4344 | 37 | 61 | 620 | 73 | 11.9 | 4.3 | 4.1 | 2.0 | 1.08 | 0.95 | 0.16 |
| Conn DM | 1646 | 22312 | 2064 | 4670 | 66 | 515 | 1041 | 60 | 24.5 | 6.9 | 10.3 | 22.5 | 1.54 | 0.70 | 0.76 |
| Conn 2/3 DM | 1064 | 13947 | 4680 | 6994 | 32 | 364 | 893 | 132 | 19.1 | 2.7 | 9.8 | 13.8 | 0.82 | 0.56 | 0.86 |
| Conn 1/3 DM | 2353 | 38828 | 7068 | 8565 | 88 | 251 | 1154 | 297 | 45.8 | 12.8 | 17.8 | 27.3 | 1.73 | 0.94 | 0.93 |
| Conn Soil | 4402 | 53030 | 11016 | 9607 | 124 | 217 | 499 | 31 | 45.8 | 12.7 | 7.2 | 12.9 | 1.31 | 0.99 | 0.64 |
| Ill DM | 1656 | 24740 | 23088 | 7798 | 4 | 102 | 5488 | 160 | 63.4 | 7.1 | 27.2 | 3.7 | 1.92 | 0.77 | 0.29 |
| Ill 2/3 DM | 2008 | 31113 | 20928 | 7436 | 9 | 111 | 6026 | 127 | 70.9 | 8.7 | 19.9 | 4.2 | 1.63 | 0.65 | 0.37 |
| Ill 1/3 DM | 2674 | 33145 | 20135 | 6619 | 16 | 113 | 4779 | 105 | 59.1 | 9.8 | 16.6 | 2.0 | 0.98 | 0.80 | 0.30 |
| Ill Soil | 3356 | 64824 | 14267 | 4712 | 28 | 101 | 446 | 57 | 56.4 | 14.2 | 9.7 | 2.7 | 1.36 | 0.81 | 0.27 |
| Mich DM | 4762 | 31098 | 16749 | 4920 | 8 | 113 | 7818 | 174 | 137.0 | 20.1 | 18.8 | 2.3 | 1.44 | 0.00 | 1.64 |
| Mich 2/3 DM | 5065 | 21350 | 18271 | 6147 | 14 | 125 | 6958 | 244 | 126.8 | 19.4 | 27.4 | 5.4 | 1.87 | 0.00 | 1.77 |
| Mich 1/3 DM | 4882 | 20959 | 19457 | 6604 | 40 | 153 | 3965 | 219 | 83.1 | 19.0 | 40.4 | 7.7 | 2.30 | 0.21 | 1.40 |
| Mich Soil | 6090 | 35445 | 9172 | 7490 | 61 | 110 | 496 | 34 | 44.1 | 10.8 | 15.6 | 3.8 | 1.15 | 0.03 | 0.43 |

*Values are averages of analysis of 5 replicate treatment pots.

Table C4 (continued)

| | P | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Minn DM | 1647 | 29225 | 24706 | 5837 | 3 | 101 | 2069 | 207 | 46.7 | 13.1 | 18.2 | 3.7 | 1.85 | 0.86 | 1.41 |
| Minn 2/3 DM | 3033 | 38669 | 20073 | 6392 | 39 | 127 | 2929 | 62 | 39.4 | 8.7 | 13.6 | 3.7 | 1.53 | 0.97 | 0.98 |
| Minn 1/3 DM | 2246 | 46295 | 20128 | 5470 | 47 | 142 | 2028 | 57 | 39.9 | 8.7 | 14.2 | 4.7 | 1.70 | 0.91 | 0.71 |
| Minn Soil | 2296 | 52815 | 19137 | 4936 | 57 | 150 | 2021 | 60 | 37. | 8.8 | 11.4 | 4.2 | 1.44 | 0.95 | 0.62 |
| Miss DM | 1146 | 44047 | 16974 | 4631 | 20 | 137 | 1025 | 186 | 26. | 8.8 | 12.9 | 4.2 | 1.56 | 33.01 | 0.25 |
| Miss 2/3 DM | 3002 | 52528 | 18190 | 4350 | 49 | 118 | 1462 | 75 | 35.9 | 8.6 | 12.9 | 1.8 | 1.37 | 0.72 | 0.30 |
| Miss 1/3 DM | 2797 | 55073 | 19056 | 4326 | 73 | 146 | 1362 | 58 | 37.4 | 9.7 | 13.5 | 3.4 | 2.53 | 0.92 | 0.64 |
| Miss Soil | 3173 | 57965 | 17489 | 4084 | 67 | 145 | 1289 | 57 | 41.3 | 10.1 | 12.7 | 3.4 | 1.46 | 0.69 | 0.72 |
| NJ DM | 4776 | 56383 | 11262 | 7250 | 70 | 271 | 792 | 90 | 187.1 | 13.7 | 26.8 | 26.1 | 1.94 | 1.07 | 1.38 |
| NJ 2/3 DM | 4360 | 41887 | 9087 | 6912 | 105 | 344 | 945 | 75 | 200.8 | 18.0 | 20.9 | 27.2 | 2.46 | 1.38 | 1.47 |
| NJ 1/3 DM | 3171 | 49530 | 9635 | 7302 | 112 | 305 | 611 | 369 | 102.9 | 12.4 | 19.6 | 28.6 | 1.85 | 1.28 | 0.85 |
| NJ soil | 4736 | 21205 | 14612 | 13848 | 328 | 290 | 1387 | 128 | 34.8 | 13.1 | 15.9 | 25.6 | 1.49 | 1.16 | 0.50 |
| NY DM | 1465 | 45275 | 19491 | 4921 | 20 | 93 | 4594 | 190 | 128.8 | 22.6 | 28.7 | 3.1 | 1.08 | 0.83 | 1.98 |
| NY 2/3 DM | 1410 | 35758 | 24706 | 4253 | 23 | 160 | 2538 | 178 | 76.5 | 18.4 | 17.6 | 4.7 | 1.34 | 1.13 | 1.53 |
| NY 1/3 DM | 2563 | 38626 | 21107 | 4790 | 17 | 135 | 1367 | 239 | 108.5 | 23.1 | 16.5 | 5.5 | 1.18 | 0.29 | 2.78 |
| NY Soil | 1611 | 49907 | 7293 | 6716 | 31 | 103 | 273 | 151 | 67.6 | 9.8 | 9.6 | 5.2 | 0.76 | 0.00 | 1.13 |

Table C4 (concluded)

| | P | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ohio DM | 5198 | 42779 | 13962 | 4599 | 7 | 102 | 3990 | 94 | 79.4 | 9.7 | 15.1 | 6.2 | 1.53 | 0.00 | 5.04 |
| Ohio 2/3 DM | 5295 | 37468 | 13999 | 4963 | 29 | 132 | 3738 | 85 | 86.3 | 10.5 | 15.9 | 6.7 | 1.29 | 0.00 | 5.63 |
| Ohio 1/3 DM | 3953 | 33849 | 17666 | 5387 | 33 | 145 | 2900 | 115 | 78.2 | 10.1 | 14.3 | 3.5 | 1.43 | 0.00 | 4.75 |
| Ohio Soil | 1916 | 54631 | 7613 | 6941 | 36 | 133 | 198 | 112 | 48.6 | 6.8 | 9.2 | 2.4 | 0.90 | 0.00 | 0.74 |
| SC DM | 1871 | 71523 | 8149 | 4455 | 80 | 152 | 19732 | 259 | 151.8 | 9.7 | 82.1 | 2.7 | 1.31 | 1.07 | 0.81 |
| SC 2/3 DM | 1273 | 70781 | 7703 | 4976 | 52 | 114 | 11695 | 251 | 77.7 | 8.7 | 73.8 | 4.9 | 1.86 | 1.17 | 0.56 |
| SC 1/3 DM | 1040 | 56949 | 7674 | 5885 | 73 | 148 | 14449 | 224 | 79.8 | 9.0 | 58.0 | 4.4 | 1.42 | 1.03 | 0.60 |
| SC Soil | 428 | 16763 | 6031 | 3432 | 13 | 52 | 587 | 38 | 13.8 | 2.1 | 5.3 | 0.9 | 0.61 | 1.04 | 0.12 |
| Wauk. | 2086 | 43115 | 17153 | 4467 | 30 | 131 | 707 | 97 | 26.9 | 6.9 | 12.6 | 4.0 | 1.31 | 1.12 | 0.49 |
| Port B. | 2164 | 73840 | 17610 | 4115 | 14 | 111 | 335 | 186 | 28.7 | 7.7 | 9.7 | 3.8 | 0.99 | 0.89 | 0.55 |
| Nicol. | 2012 | 62522 | 17579 | 4946 | 11 | 98 | 815 | 89 | 40.8 | 9.3 | 14.4 | 5.0 | 2.02 | 1.03 | 0.59 |

Table C5

Elemental Analysis of Selected Second Crop Barley.* Values Expressed as µg/g.

| | P | K | CA | MG | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mich DM | 2616 | 58216 | 19715 | 3501 | 20 | 102 | 4293 | 95 | 118.3 | 22.5 | 33.3 | 2.7 | 0.92 | 0.67 | 2.23 |
| Mich 2/3 DM | 2825 | 57980 | 19488 | 3635 | 7 | 94 | 3475 | 95 | 95.7 | 23.5 | 40.1 | 2.9 | 0.76 | 0.62 | 2.05 |
| Mich 1/3 DM | 3052 | 64913 | 19746 | 3323 | 12 | 141 | 1916 | 78 | 72.7 | 21.7 | 31.5 | 2.9 | 0.60 | 0.64 | 1.72 |
| Mich Soil | 5442 | 68855 | 11955 | 4250 | 36 | 64 | 324 | 128 | 46.7 | 11.9 | 53.7 | 2.8 | 1.02 | 0.72 | 0.66 |
| NY DM | 1887 | 73461 | 20898 | 3422 | 11 | 67 | 2262 | 155 | 161.2 | 20.0 | 52.0 | 2.8 | 0.67 | 0.55 | 4.37 |
| NY 2/3 DM | 1897 | 74364 | 22777 | 2803 | 13 | 71 | 1327 | 146 | 126.4 | 21.7 | 38.2 | 2.8 | 0.58 | 0.52 | 3.85 |
| NY 1/3 DM | 2274 | 74590 | 20783 | 3177 | 15 | 102 | 757 | 181 | 118.4 | 20.6 | 52.0 | 7.3 | 1.71 | 0.46 | 4.78 |
| NY Soil | 2107 | 68023 | 10384 | 4341 | 12 | 69 | 275 | 50 | 26.4 | 6.8 | 38.9 | 0.00 | 0.15 | 0.21 | 0.45 |
| Ohio DM | 3227 | 68632 | 22479 | 3064 | 7 | 96 | 3051 | 32 | 46.5 | 15.0 | 39.7 | 0.5 | 0.50 | 0.31 | 3.25 |
| Ohio 2/3 DM | 2735 | 63423 | 19309 | 3086 | 6 | 83 | 2195 | 36 | 43.7 | 13.9 | 27.9 | 2.2 | 0.82 | 0.47 | 3.03 |
| Ohio 1/3 DM | 2613 | 63682 | 20534 | 2957 | 12 | 98 | 1334 | 43 | 36.1 | 13.8 | 25.6 | 2.3 | 0.51 | 0.44 | 2.56 |
| Ohio Soil | 2232 | 78218 | 9662 | 4050 | 12 | 102 | 161 | 68 | 28.7 | 4.7 | 30.9 | 0.4 | 0.35 | 0.30 | 0.44 |
| Wauk. | 3069 | 53863 | 14846 | 3774 | 34 | 93 | 1833 | 64 | 23.0 | 5.9 | 20.7 | 1.8 | 1.32 | 0.50 | 0.23 |
| Port B. | 2807 | 73559 | 16849 | 4272 | 7 | 105 | 533 | 62 | 20.4 | 7.2 | 32.2 | 1.8 | 0.88 | 0.88 | 0.38 |
| Nicol. | 2780 | 58599 | 16691 | 4786 | 11 | 86 | 2381 | 65 | 30.1 | 8.3 | 25.0 | 2.2 | 1.47 | 0.56 | 0.55 |

*Values are averages of analysis of 5 replicate treatment pots.

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Gupta, S C
The agricultural value of dredged material / by S. C. Gupta ... [et al.], Agricultural Research Service, North Central Region, U. S. Department of Agriculture, St. Paul, Minn. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
134, [31] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-78-36)
Prepared for Office, Chief of Engineers, U. S. Army, Washington. D. C., under DMRP Work Unit No. 4C03.
References: p. 129-134.

1. Agricultural engineering. 2. Dredged material. 3. Dredged material disposal. 4. Sediment analysis. I. United States. Agricultural Research Service. North Central Region. II. United States. Army. Corps of Engineers. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-78-36.
TA7.W34 no.D-78-36